Politecnico di Torino

Politecnico di Torino

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FROM CARBON TO ALUMINUM

Evolution of materials from the initial prototype phase to a project phase

Case of study: Design of a hood skeleton of a luxury vehicle

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PREFACE

In September 2022 I started a collaboration for the development of my master thesis with the company Magna Steyr Italia in the engineering department, which aim is the design of the body in white for the passenger vehicles.

Together with the hosting company, we decided to focus the topic on designing a specific component for the vehicle and, specifically, on the internal skeleton of a front hood which was, to us, the most complete component for showing all the design differences that have to be carried out according to the material that has to be used, then, in the production process.

The two materials that were considered were the aluminum and the carbon fiber-reinforced composite; the two materials have completely different properties and production processes. Then, two different designs have to be considered, each one with specific features and precautions in order to prevent any damages during the creation of the final part.

We decided to write this thesis introducing all the topics in the firsts chapters and then explaining, all the work done during the period I worked in the company, in the last chapter.

There will be an introductive chapter on the vehicle in general, concerning all the classification of the different types of vehicles, the homologation norms, and the star rating process. The attention is then moved, in the second chapter, on the body in white, in which there will be a definition, an explanation of how it is composed, and a declaration of the materials used with a briefly focus on the modularity of the underbody-platforms. Furthermore, an introduction of the two materials separately is carried out; for both aluminum and carbon fiber-reinforced composite an explanation on which are the main properties, and which are the production processes, and the joining methods is done, with a focus on those used by the company for their projects.

Finally, a description about my case study is done; in particular about all the constrains considered both coming from norms and regulations and from other component of the vehicle; a detailed presentation of the design sequence, over which I worked, separately for aluminum and for carbon is performed. Moreover, a presentation about the fastening methods used in the project and about the reinforcement designed, specifically, for both the configurations is done. Finally, a comparison between the final results of the two materials in order to show and justify the visible differences closes the thesis.

COMPANY OVERVIEW: THE MAGNA WORLD

My master’s degree thesis was developed in collaboration with the company Magna Steyr Italia, which is in Rivoli, outside of Turin.

Magna Steyr, to which the Italian division belongs, is a company owned by the Canadian group Magna International since 2001 when it acquired most of the Austrian group Steyr-Daimler-Puch AG which had several industrial fields of interests: from vehicle of any type to tractors, planes, military vehicle and even some light weapons.

Magna international is a leader company in the production of vehicle production in north America and oversees producing and assembling systems and components for vehicle that are supplied to big car companies such as General Motors, Ford Motor Company, Stellantis, BMW, Mercedes, Volkswagen, Tesla Motors.

Magna Steyr has six engineering department across Europe and Asia, in Austria, Germany, France, Italy, China, Japan and India.
The company offers several services, from the design of the vehicle to a complete vehicle integration up to a safety engineering of the vehicle and following testing.

The Rivoli site of Magna Steyr to which I had the pleasure to conduct my stage and to develop my thesis is divided into two departments:

- Surface department: supports the styling centers of the customers and provides the aesthetic side by sketching and developing of the “skin” of the vehicle.
- Engineering department: develops the vehicle from an initial approach in which shapes the styling surface up to a complete development of BIW, internal and external fictions, doors, and closures.

In Figure 1 we can see some one-off and low production vehicles developed by Magna Steyr

Figure 1: Magna Steyr one-off and low production vehicles examples

The first vehicle in the picture is the KSU GAZAL 1 for which Magna Steyr Italia has developed the full vehicle engineering, starting from the platform of the Mercedes G-Class, and homologation process considering the market of application which was the Saudi one.

The second and the third ones are from WMOTORS and are the LYKAN HYPERSPORT and the FENYR SUPERSPORT for which Magna Steyr Italia has taken the full responsibility for the surfacing process, engineering, and manufacturing in seven vehicles for the first and 26 for the second.

The last vehicle is the ICONIQ 7 which is a one-off vehicle for which Magna Steyr Italia was chosen for the complete external and internal surface and engineering development.

VEHICLE INTRODUCTION

In this first chapter I would like to introduce what is a vehicle, which are the classification in which they are subdivided, and which is our class of interest.

I would like to talk also about homologation rules, and which are the minimum safety standard imposed by the regulatory authority; then I would like to give an overview on the EURONCAP and on the different type of crash test that a manufacturer has to face in order to obtain the homologation.

VEHICLE DEFINITION AND CLASSIFICATION

“A motor vehicle is any power-driven vehicle which is normally used for carrying persons or goods by road or for drawing, on the road, vehicles used for the carriage of persons or goods.” [1] .

All vehicles are classified according to their type, use, masses, powers, and maximum speed.

For what concern the international classification, across the European Union and member states inside and outside Europe, the vehicle classification is the one adopted by the UNECE[1].

According to this classification, we can distinguish several classes of vehicle [1]:

- Class “L” vehicle are all the motor vehicles with less than four wheels.

  Inside this macro category we have seven more classes which divide the vehicle furthermore according to the number of wheels (3 or 4), to the engine displacement (below or over than 50cc) and to the maximum speed reached (below or over 45 Km/h).
- Class “M” vehicle are all the power-driven vehicles having at least four wheels and used for the carriage of passengers.

  Inside this class we have three more categories which divide the vehicle according to the number of seats apart from the driver (more or less than 8) and to the mass of the vehicle (below or over 5t).
- Class “N” vehicle are all the power-driven vehicles having at least four wheels and used for carriage.

  n-class vehicles are divided in three more sub-groups according to their mass (below 3.5t, between 3,5t and 12t and above 12t).

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[1] UNECE is the United Nations and European Economic Commission

- Class “O” vehicle includes trailers and semi-trailers which are again subdivided in four more groups according to their mass.
- “Special purpose vehicle” which involves a vehicle listed in the previous categories for which a special body arrangement is necessary.
- Class “T” vehicle which includes any motorized agriculture or forestry vehicle having two axles and a maximum design speed not below 6km/k.
- Class “G” vehicle which includes off-road vehicles.

M1-CLASS VEHICLES

In this section I will develop more in deep the m-class vehicle and in particular the M1 subgroup which includes all the vehicles used for carriage and passengers which have not more than eight seats apart from the driver’s one.

Those vehicles are the subject of interest of Magna Steyr Italia which, as said previously, offer to clients the complete development of the BIW.

Inside this class of vehicles, we can make a distinction according to the diverse types of bodies style and configuration. In particular we can identify three groups of vehicles, which differs for the number of side pillars[2] they have and, as a consequence, for the way that the space for the engine, for the passengers and for the luggage is divided.

Moreover, there is a further segmentation that has been introduced by the European Commission to subdivide the market according to some distinctive criteria of each segment like engine size and length.

VEHICLES CLASSIFICATION IN VOLUMES

The three-volumes design configuration, as reported in Figure 2 [2], have a separate compartment for the engine, the passengers, and the luggage. They are designed with three pillars which supports the passenger’s volume while the tailgate is hinged below the rear windscreen.

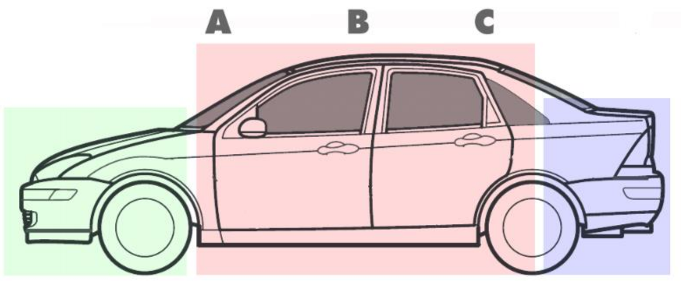

Figure 2: Profile of a three-volumes sedan vehicle

[2]Pillars are vertical elements which are stiff enough to connect the top frame (roof) with the ladder frame (underbody)

Inside this configuration of vehicles, we can find the Sedan cars, which have front engine and generally four passengers' doors; and the Coupe' cars, Figure 3 [3], which is characterized by a sloping rear roofline and generally one row of seats and two passengers' doors.

This is simple definition for the distinction of a Sedan and of a Coupe' car.

Despite this, we can have also two-doors sedans or four-doors coupes.

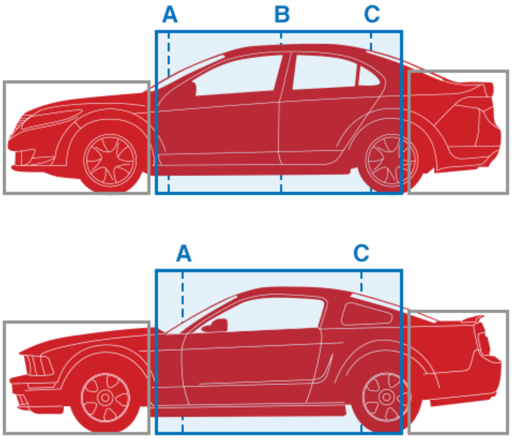

Figure 3: Profile of a Sedan vehicle (upper) and a Coupe' vehicle (lower)

The two-volumes design configuration are characterized by having a separate compartment for the engine but an integrated compartment for passengers and luggage.

A distinctive feature of this type of configuration is that the tailgate is hinged at the roof level, differently from the three-volume configuration.

Inside this configuration of vehicle, we can find Hatchback cars and Station Wagon cars.

Despite the similarities between the two types of vehicles, the Station Wagon are more used to have a pillar more than the hatchback (D-pillar); moreover, Station Wagon have a rear extended roof without having any slope, this allow to have a higher cargo volume, differently from hatchbacks which are characterized by a sloping roof behind C-pillar[3].

In Figure 4 [2] we can see the main external differences between the two vehicles.

Other internal differences can be related to a flatter floor, for increasing cargo capacity, in Station Wagons that can also have a row of seats more respect to Hatchbacks.

[3] Hatchbacks can be called Liftback when the roof is steeply sloped (from 45 up to 5 degrees)

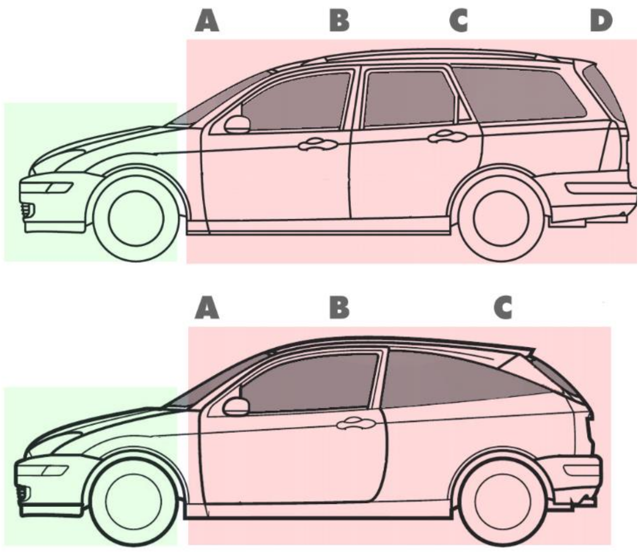

Figure 4: Profile of two-volumes Station Wagon (upper) and Hatchback (lower)

Last, the single-volume design configuration is characterized by the inclusion in a single volume the engine, passengers and luggage compartments as can be seen in Figure 5. inside this configuration of vehicles, we can find both passenger cars and minivans.

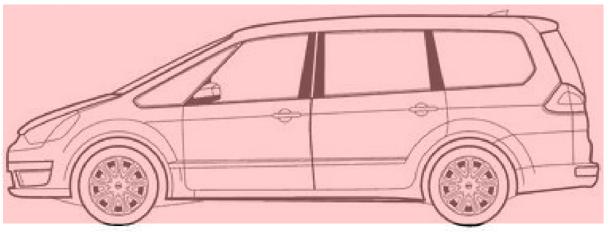

Figure 5: Profile of single-volume configuration vehicle

EUROPEAN CAR SEGMENTATION

For what concern the vehicles market segmentation in Europe, there is not a well-defined regulation. The different segments were mentioned for the first time by the European Commission in the case number IV/M.1406 – Hyundai/Kia [4]; in this occasion the different classes where just presented without a univocal definition and the difference were based on the vehicle length and on the engine displacement, not on a weight basis.

Over the years, also other organization like Euro NCAP has provided their classification. The lack of a single definition has provided overlaps of segment defined by Europe Commission, Euro NCAP[4] but even respect to the Segments provided by the US EPA[5].

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[4] European New Car Assessment Program (Euro NCAP) is a voluntary vehicle safety rating program.

[5] Environmental Protection Agency (EPA) is an independent executive agency of the United States federal government aimed to environmental protection.

The segmentation provided by the European Commission is reported below with the addition of a brief explanation of each category which come from other organization segmentation or by market view of different car manufacturers:

- A-segment: mini cars which ranges from 2.7 to 3.7 meters of length.
- B-segment: small cars which ranges from 3.7 to 4.2 meters of length.
- C-segment: medium cars which ranges from 4.2 to 4.6 meters of length.
- D-segment: large cars.
- E-segment: executive cars.
- F-segment: luxury cars.
- S-segment: sports coupés.
- M-segment: multipurpose cars which include minivans and cargo vans.
- J-segment sport utility cars: cars which at the same time can accommodate passengers and shows off-road vehicles characteristics.

In Table1 I have made a recap about how the car segments are perceived by the three principal organization. In this table we can notice the difference between each classification and how this is very sensible to the parameter used to creates segments.

In the last column I have reported a picture in order to identify each class with a real vehicle.

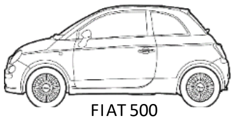
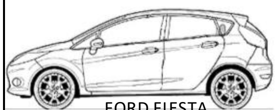
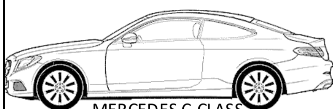
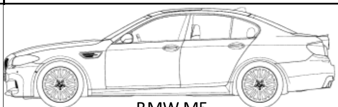
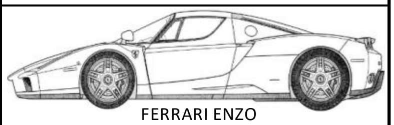
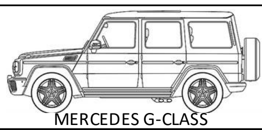
CAR MARKET SEGMENTATION			
EUROPEAN COMMISSION	**EURO NCAP**	**US EPA**	**EXAMPLE**
A-segment mini cars	Supermini	Minicompact cars	 FIAT 500
B-segment small cars		Subcompact cars	 FORD FIESTA
C-segment medium cars	Small family cars	Compact cars	 WOLKSVAGEN POLO
D-segment large cars	Large family cars	Mid-size cars	 MERCEDES C-CLASS
E-segment executive cars	Executive cars	full-size cars	 BMW M5
F-segment luxury cars	-		 PORSCHE PANAMERA
S-segment sports coupés	Roadster sport	-	 FERRARI ENZO
M-segment multipurpose cars	Multi Pourpose Vehicle	Minivans	 FORD GALAXY
J-segment sport utility cars	Off-road cars	SUV	 MERCEDES G-CLASS

Table 1: Car Market Segmentation

HOMOLOGATION REGULATION

Homologation rules are imposed by the regulatory authority in order to set minimum standards for safety of driver, passengers and even for the pedestrian and even other street occupants.

European Union, over the years, has gained a position of leader in homologation requirement emission by setting directive and regulations that has to be taken as guidelines by each member state on which create his own laws.

This is important in order to create a harmonization of national laws inside all the European Union in order to avoid any obstacle to the public circulation.

For the purposes of this thesis, I will summarize some directives which are more relevant to the topic developed and I will subdivide them in visibility and passive safety requirements.

VISIBILITY

When dealing with the design of the car structure is of extremely importance to guarantee the proper visibility to the driver and prevent that any substructure will interfere with it; so, to guarantee the safety of people inside and outside of the vehicle.

To develop all the topic regarding to the visibility, is important to make some recap regarding the eye functioning; in particular is important to point out that the maximum sight ability occurs few degrees around sight line. Then, without any motion of the head, and looking it from the top view as the left representation of Figure 6, we can have a detailed field of view rotating laterally (to left and right) our eyes for a total of ±30° respect to the standard line of sight; if the object is outside of this range, we have to make an additional motion of the head. In this case we can achieve a field of view in the range of ±45° around the head centerline with a comfortable motion of the head, while we can achieve even ±60° range with a maximum head rotation.

Looking the head from a side view, as we can see in the right representation of Figure 6, we can understand which is the reachable field of view in vertical direction; in particular we can reach a range of ±15° with a comfortable eyes' rotation, while as maximum range reachable with simply rotation of the eyes, we have +25°/-30°. If, instead, the object is outside of this field of view, we can achieve a range of +50/-70 degrees with a rotation of the head.

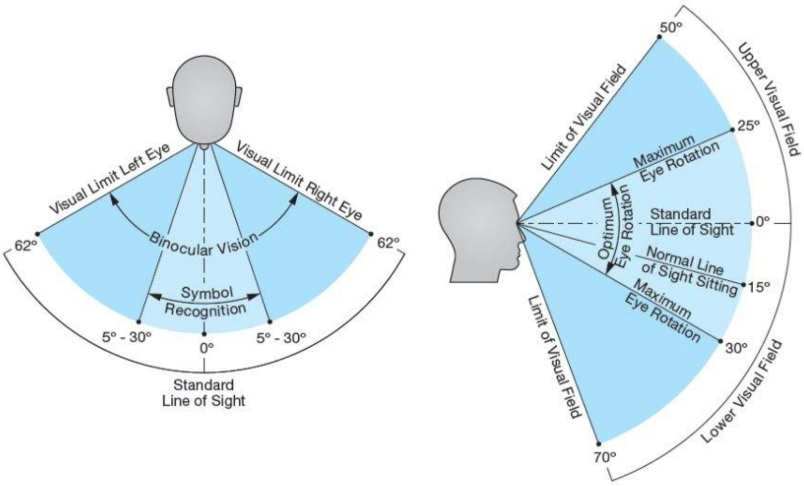


Figure 6: Representation of the field of lateral (left) and vertical (right) field of view.

Considering now each eye separately, the definition of field of view changes as also the range that each eye can reach.

In particular we consider a range of sight of each aye which goes from +45° to -90°, also considering that the nose is in the middle of the sight line and for this can be an obstacle.

Putting together the range of view for both eyes, as reported in Figure 7, we can identify four different ranges; the range of view of each single eye is named monocular field of view (MFOV), in figure below we can see the left (red) and the right one (green); the region where the field of view of both eyes overlaps is called binocular field of view (BFOV) while the summation of both fields of view is called ambiocular field of view (AFOV).

During normal drive, we exploit the BFOV cause allow to appreciate better the distance of the object on front of us.

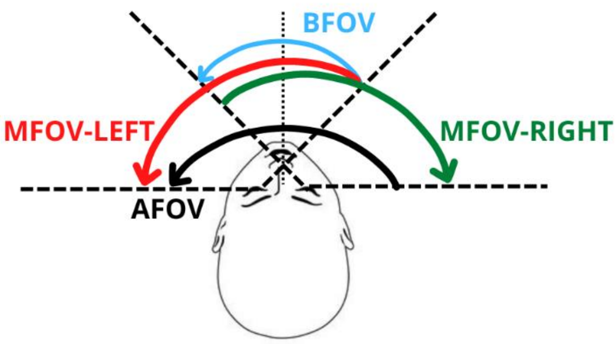


Figure 7: Representation of the existing fields of view

Concerning our vehicle class of interest, M1, the visibility constraints has played a fundamental role in the safety of the vehicle and for this, several standards were developed by the European Union regarding for example the dimension of the windshield; about the obstruction of non-transparent[6] part, especially front doors, hood, roof, and pillars; about the number of the pillars in front of the driver.

No directives are present regarding passengers' windows and rear windscreen.

Before briefly explaining those directives, it is important to explain which are the reference point on which they are developed.

The reference frame used is a XYZ reference frame which is centered in R-point[7] of the driver.

A particularly key role is played by the so called "viewpoint" or "V-point" on which position all the European directives based on visibility is based. Their position depends strictly on the position and the inclination of R-point and the reference frame; in Table 2 we can find the mutual position of viewpoint V1 and V2 for a seat inclined of 25° [5].

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[6] Transparent area is defined as a windscreen or other glazed surface whose light transmittance at right angles is not less than 70% [5].

[7] R-point is a point defined by the car manufacturer as seating reference point at design stage of the seats.

V-point	X	Y	Z
V1	68 mm	-5 mm	665 mm
V2	68 mm	-5 mm	589 mm

Table 2: V-points position for a seat inclined of 25 degrees.

For what concern the front windshield on the driver side [5], it has to include some point that are:

- Horizontal datum point projected from V1 on to the windshield and 17° to the left and one 7° upper respect V1.
- datum point projected from V2 and 5° below it.

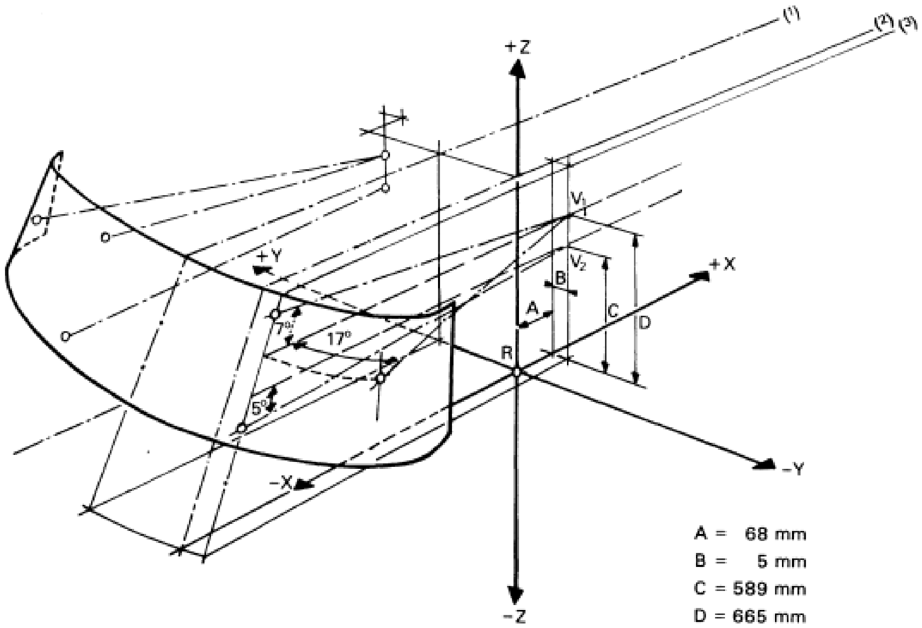

Figure 8: Windshield datum point

For what concern the obstruction [5], directives strictly regulate what can undermine the driver sight.

In particular is reported that vehicle cannot have more than two A-pillars, and apart from that, moveable part, wipers and mirrors, no obstruction are allowed in 180° field of view in front of the driver.

In particulate, all the components apart the one said previously must not exceed three planes passing from V2 and inclined of 4° from the horizontal direction.

For better understanding of what said, Figure 9, can helps. As can be seen, the three plane that are imposed, must not intersect any object that is declared as non-transparent like the hood (our case of interest) or the lateral panel of the driver door or of the front passenger door.

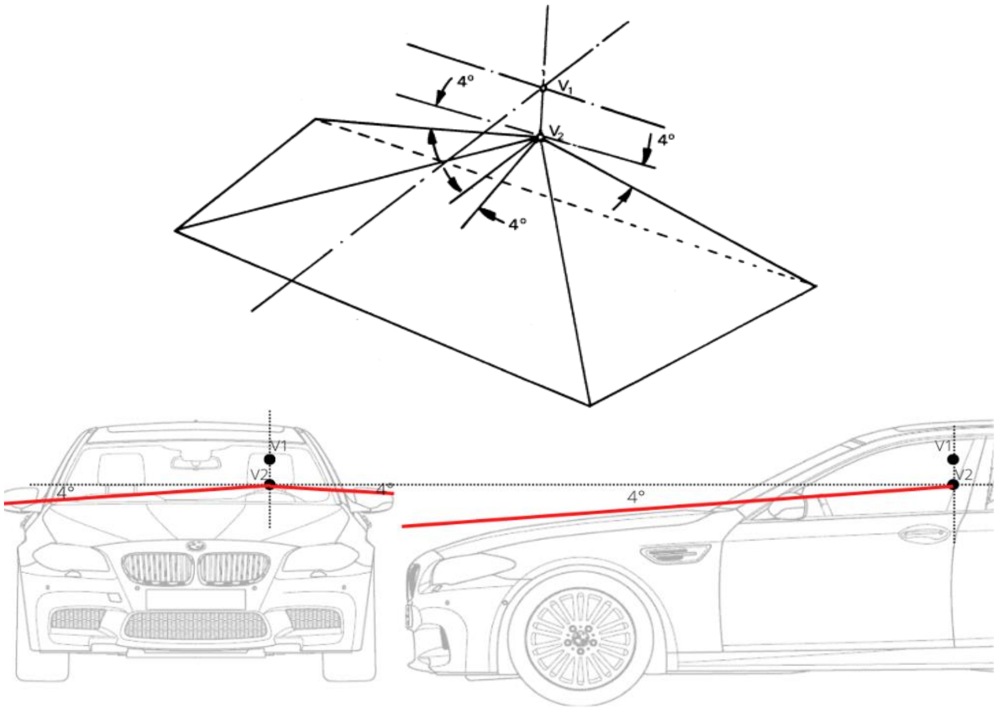

Figure 9: Obstruction requirements practical

Main importance has the A-pillar obstruction [5] to driver field of view; in particular, for what concern the driver side its angle of obstruction shall not exceed 6°, while for passenger side can be assumed equal if the positioning of the two pillars is symmetrical.

To calculate the value of the angle of obstruction, two horizontal sections of the A-pillar should be superimposed on the same plane.

To calculate those section, we have to make a step back and define the so-called P-points which are the point around which driver's head rotates on horizontal plane at eye level, and Pm-point which is the intersection point of P1 and P2 with a vertical line passing from R-point.

Now we can define the way the two sections are found:

- the first section (section A) is made starting from Pm-point and drawing a plane which has a 2° inclination respect to the horizontal plane passing from Pm.
- the second section (section B) is made repeating the previous procedure but with a plane inclined of -5° respect to a horizontal plane passing from Pm.

The angle which is regulated by the European directive is the angle between the parallel centered in E2 of the line centered in E1[8], perpendicular to the line E1-E2 and tangent to outer edge of S1; and the line centered in E2, perpendicular to E1-E2 and tangent to the inner section of S2.

[8] Point E1, E2, E3 and E4 represents the centers of driver eyes in head position P1 and P2.

For what concern the obstruction of the driver sight to the A-pillar on the driver side the procedure is similar but considering points E3 and E4.

We can better understand the obstruction procedure of A-pillars in Figure 10 [5].

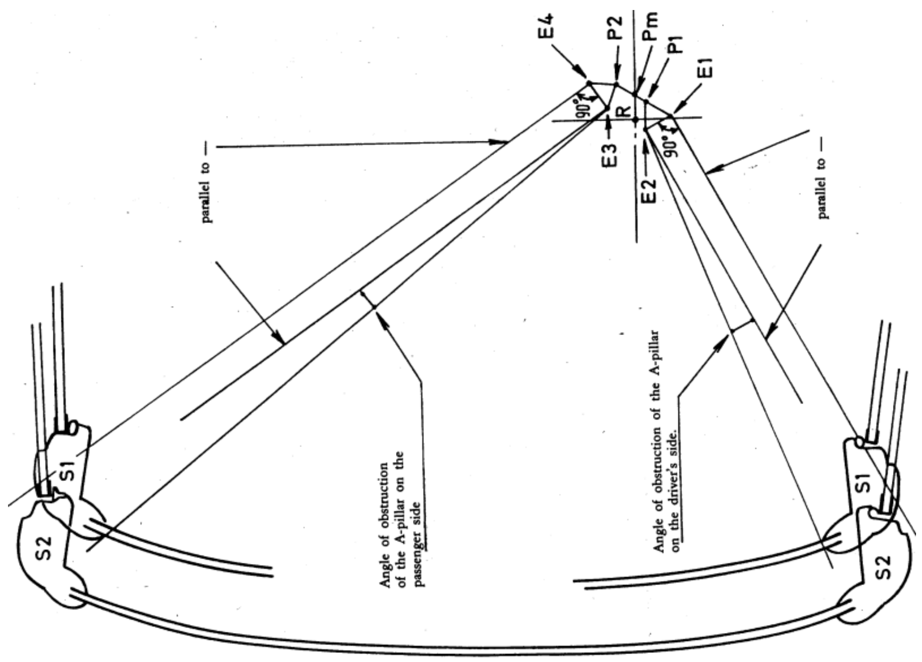

Figure 10: Representation of the A-pillar obstruction procedure

Mirrors too are regulated by the directive, both in terms of dimension and in terms of field of view that they allow the driver to have [6].

For what concern the dimensions, the internal mirror has to be more than 4cm high and its length should be determined by the formula $l = 15cm * \frac{1}{1+\frac{1000}{r}}$; for what concern external mirror, while the minimum height is the same of the internal one, its length can be determined by the formula $l = 13cm * \frac{1}{1+\frac{1000}{r}}$; in both cases r is the radius of curvature and has to be greater than 1200mm.

For what concern the visibility conceded by the mirrors, the internal mirror the driver has to be allowed to see an infinite rectangle, 20m wide, starting from 60m from the mirror itself; for the external mirror on driver side, it has to be possible to see an infinite rectangle, 2,5m wide, starting from 10m from the mirror, while for the passenger' side mirror, the infinite rectangle has to be 4m wide and has to start from 20m from the mirror.

With Figure 11 [6] we can have a graphic recap of the directive regulating the indirect visibility.

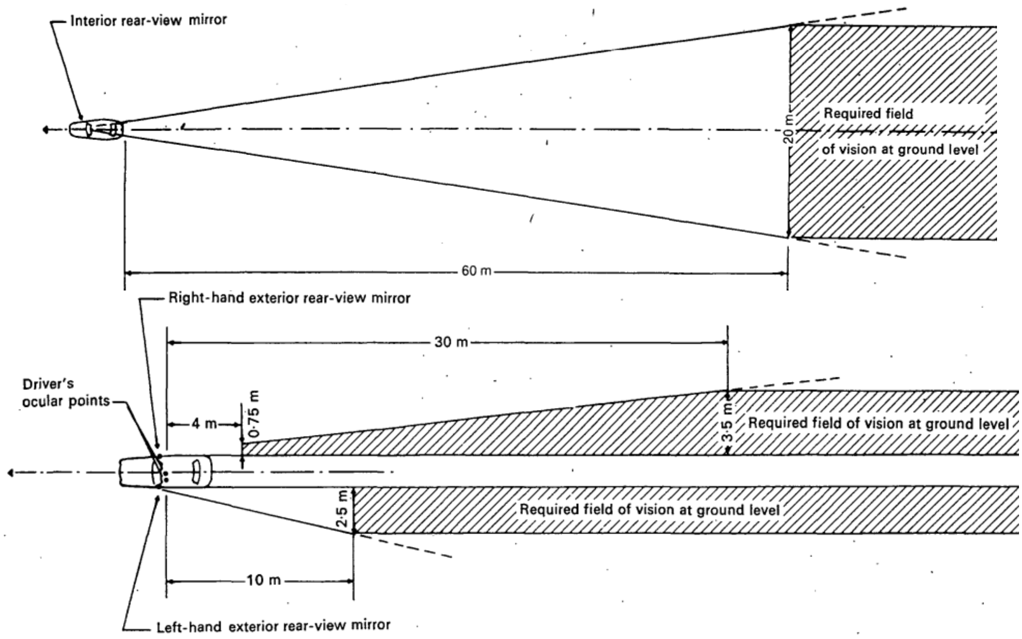

Figure 11: Indirect visibility representation

PASSIVE SAFETY REQUIRMENTS [7]

Started treating this argument, its worth of note that all the safety requirements and standards aims to mitigate the injuries to all the occupants of the vehicle that during a collision may arise.

From this we can understand that concepts regard safety accepts both that a collision may occurs and that injuries may arise from this collision; the point is to limit the probability that those injuries can become vital for the occupants of the vehicle.

The evaluation of the safety requirements can be divided in two groups: geometric and biomechanical. The first one is related with the maintenance of the cockpit integrity; following those type of rules, the structure of the car can offer a good degree of protection to the occupants. Regulators, years after the introduction of the first requirements, understood that they were not enough so the biomechanical requirements were introduced; their aim is to understand which occupants suffer the stress due to the accident and which are the dangerous limits.

The analysis of an accident is extremely important to earn information; in particular, it is important to determine which types of accident brings to death occurrence, which are the parameters that describe the severity of an impact and how the occupants get injured after an impact.

Once analyzed the accident, an equivalent test to the real accident has to be recreated; this involves the definition of object that impact the vehicle, of zone of impact and angles of impacts. For what concern the definition of the severity of the test, which is defined by the regulatory authority on the base of the limits required to protect the occupants.

Once also defined the test procedure, it is mandatory to determine some parameters, Injury Criterion, which are linked to the Injury Severity, once defined the Injury Criterion the Human Tolerance level has to be set.

For what concern the Injury criterion, European Union has adopted several according to different body segment.

HEAD

The head injury criterion (HIC) is the criterion which express the resultant of the acceleration of the center of gravity of the head.

It is based on the acceleration occurred within a temporal interval; in particular, the HIC value is obtain crossing the value of acceleration occurred with the temporal window; as we can see in Figure 12, according to the effective duration of a given acceleration we can have a value injury level, if this exceeds the black solid curve, very severe injury can occur.

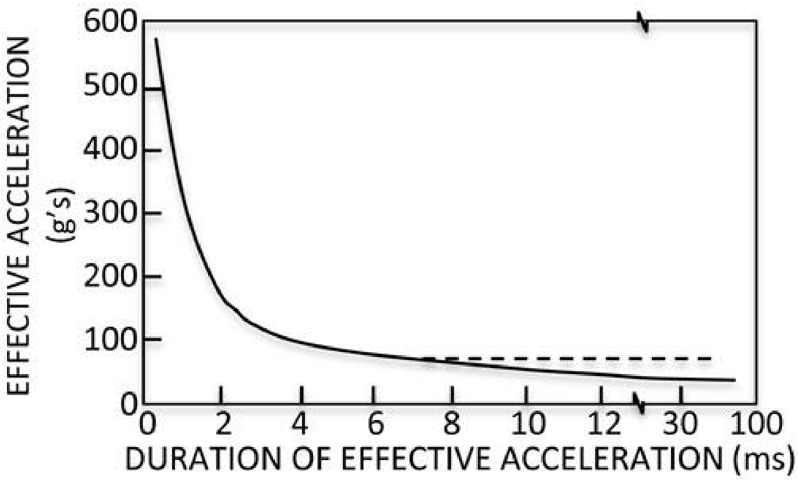

Figure 12: Head injury criteria tolerance level

NECK

For what concern the neck injury criteria, is important to underline the results of studies which underline that, low serious injuries occurs while a high number of minor injuries occurs.

When dealing with neck, we have to visualize how it can be affected by the external forces acting during a crash. As we can see in Figure 13 [7], we can identify three groups of stress that are the main sources of neck injuries; bending and extension cause the head rotate forward and backward, tension and compression due to a loading direction parallel to z-axis, shear stress which the neck undergoes due to a loading condition parallel to x-axis and so a relative motion between head and chest.

Following to European Directive, those force are regulated in order to not exceed a maximum that is prescribed as: Fx and Fz respectively for shear and tension and compression stress are limited by some curves, while My for bending and extension stresses is limited to 57Nm in extension.

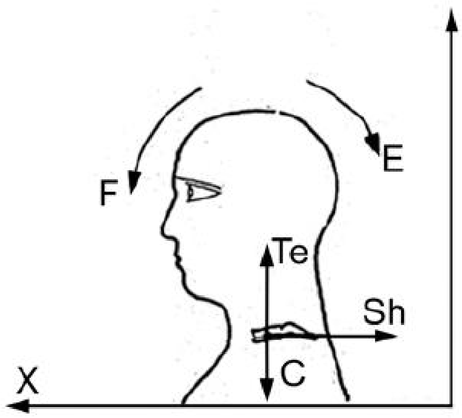

Figure 13: Neck Injury stress directions

In Figure 14 [7], we can analyze the two graphs which limits the admissible Fx and Fz action on neck during a crash.

The two graphs, shows the admissible limits for both the forces; as for HIC, the occurrence of the forces is considered together with the temporal interval in which they occur. If the forces, go over the limits serious injuries can occur.

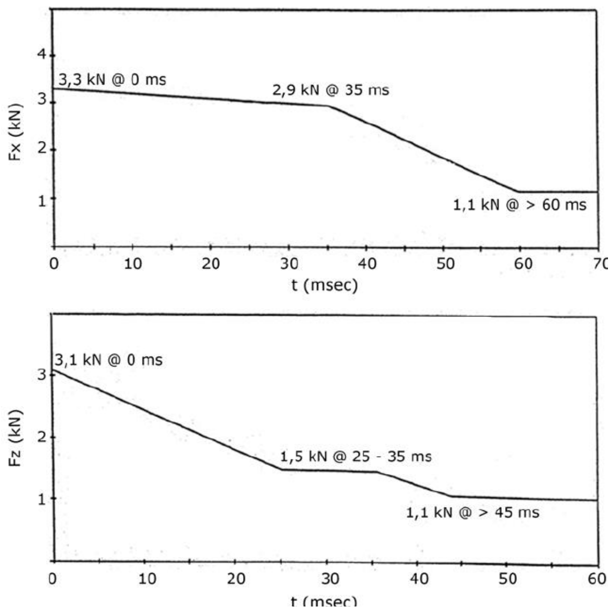

Figure 14: Neck injury limits for Fx and Fy

Now, it is important to underline the effect of a simultaneous application of Fz and My; in this way we are able to describe a more real situation respect to consider their effects separately.

In fact, their action in combination limits, even more, the human tolerance limits. This difference can be seen in Figure 15; in particular, on the left we can see the limits in tension, compression, extension, and flexion when a single force is acting; while on the right we have the same limits but when a combination of Fz and Me occurs simultaneously.

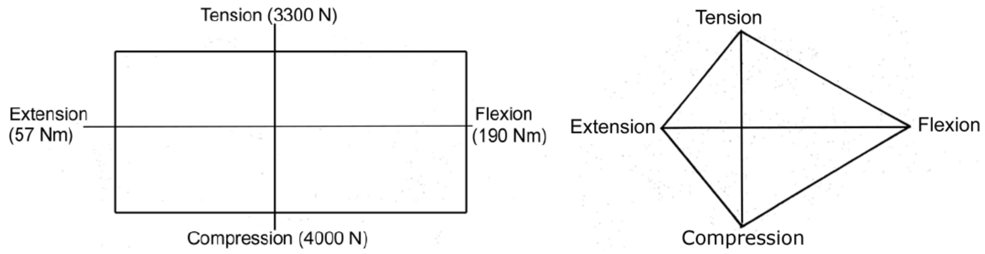

Figure 15: Conformity area for NIC

THORAX

Thoracic Injury Criteria are divided according to the type of injury, being it frontal or lateral.

For what concern the frontal impact, it can be split into two types of injuries, one concerning the internal organs and the most severe can affect arteries and heart, the other concerning rib fractures that in most severe cases can perforate internal organs.

The first type of injury is based on the acceleration to which the thorax undergoes during an impact; the second one is based on the thorax deformation.

In Figure 16 we can see the injury limits for what concern the thorax during a frontal impact; those limits were found after several tests made not only on corps but also on volunteers which were based on the application length (considered as a velocity in m/s) for acceleration. Maximum admissible found was an acceleration of 60g for 3m/s.

In picture we can find a solid line which identify the thorax injury limit and that we can find some dashed zones indicating what type of injury is more likely to occur at that level of compression and at that speed of application. The first one is the “crushing injury” indicating rib fractures, the second is the “viscous injury” which refers to soft tissue injuries like heart and lungs; the last area is “blast injuries” which indicates those injuries that came from a low compression but an instantaneous speed of occurrence.

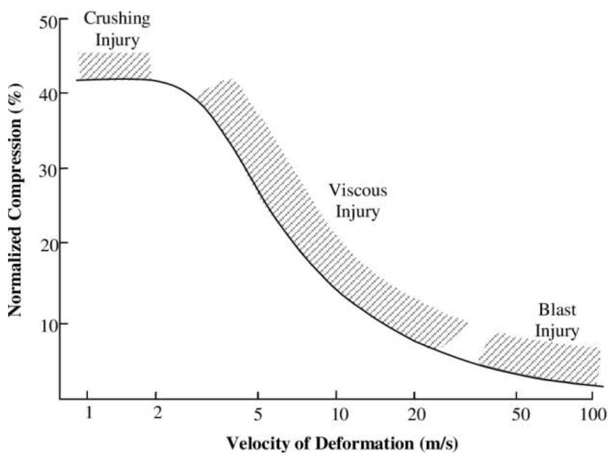

Figure 16: Thorax Injury Criteria

For what concern the lateral impact, what worries is the limited distance between the car structure and the lateral side of the thorax together with the frequency of occurrence of this type of impacts and the gravity.

To find the lateral thorax injury criteria, in Europe, fresh corps were used and dropped horizontally on several objects of different stiffness. From this, several parameters were taken into consideration and the output was the Thoracic Trauma Index (TTI) which depends on the age of the occupant to assess, the maximum value of acceleration that ribs can support under a lateral crash and the mass of the occupant respect a reference mass of 75kg.

EURONCAP

As said till know, the protection of the occupants of a vehicle is regulated by European committee but only from what the minimum standard of safety is concerned. The trend over the year was to commercialize new models of vehicle that were above those safety standards; this creates a new segment in the market that deals with the important level of passive safety.

From 1970's on, several regulatory organizations have different safety standards: in Europe just a frontal crash test of a prototype without dummies against a rigid barrier is required, just the movement of the steering column is analyzed; in USA instead, some biomechanical standard was already required but it was limited to be respected by dummies and not by real people.

Around the 1990's the NTSHA[9] conducted a survey in order to understand if customers were interested in vehicle which goes beyond safety standards imposed by regulators; the program proposed by this survey was named NCAP[10].

In 1994 and 1995 in the UK the NCAP was firstly proposed and then accepted at national level.

Only from 1997 the NCAP was shared by European Union and several organizations at national and international level, like FIA[11], and by several car manufacturers.

The Euro NCAP was born, and the aim was to transform homologation test into a way for evaluate the homologation using more severe parameters.

In fact, cars are crashed in frontal direction against a deformable barrier but even in lateral direction both against barrier and against a pole; a big innovation was introduced in 2000's when also tests for assess the pedestrian safety were introduced.

[9] National Highway and Traffic Safety Administration

[10] New Car Assessment Program

[11] Federation Internationale de l'Automobile

EURO NCAP STARS RATING

[8]

Once the tests are performed, each model assessed is assigned with an evaluation in stars which aim to declare the level of safety respect to the occupants and the pedestrian.

Those type of evaluation is customer oriented because allow him to make an easy evaluation and comparison about the level of safety of the vehicle he is looking at.

In 2009 Euro NCAP has introduced the overall evaluation on safety which is divided in four areas, and they are related to adult protection, Child protection, Pedestrian protection, and Safety assist.

The evaluation regarding to the adult safety is obtained after several tests of frontal impact, lateral impact, and whiplash test. All those tests are made in order to analyze which is the level of protection that the vehicle offers to its adult occupants. Moreover, the evaluation takes also into consideration the minimum measure planned for first aid and those for a safety extraction from a crashed vehicle.

The safety evaluation on child occupants regards three aspects: the protection given by the restrain systems in frontal and side impact tests, the modularity of the vehicle to contain child restraint systems of varied sizes and the predisposition of the vehicle for a safe transport of the children inside it.

Euro NCAP standards foresees some test for evaluate how pedestrian and cyclist are protected in an impact with a moving vehicle. In particular, tests for understanding head or leg injuries are performed. Moreover, vehicle equipped with systems that increase the safety of pedestrian, for example Emergency Automatic Braking (AEB), can earn more points in this area.

Last area that is evaluated for safety evaluation is the safety assist, which include all those technologies that helps the driver to increase his safety and the safety of all the occupants of the street, either other vehicle or pedestrian. It includes AEB car-to-car systems, lane keeping, speed limiter and others.

Each of the four areas is equipped with a maximum score, this is then averaged on the four areas and then, according to the point reached by each vehicle, a score in star is assigned. In Figure 17 [9] we can see all the rating process starting from the score in each area, passing for the weighting factor assigned to each area up to the assignment of the stars.

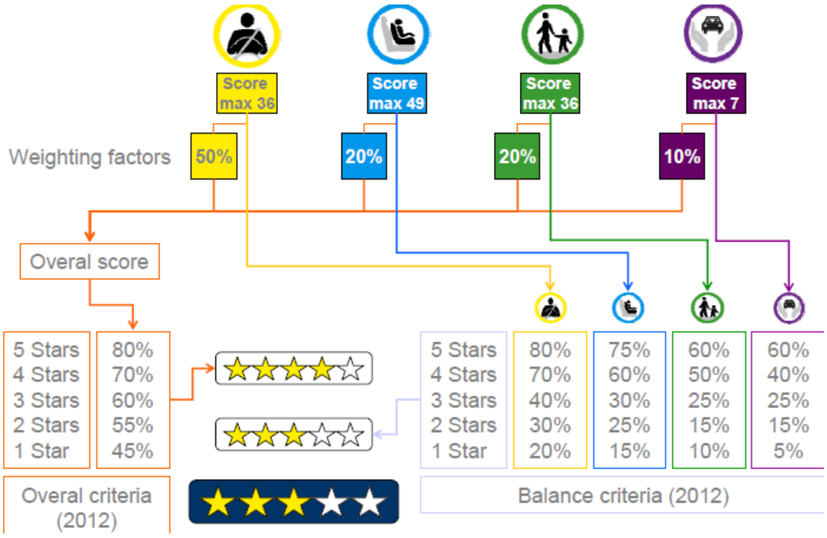

Figure 17: Euro NCAP stars rating.

Overall score is influenced by penalties that can be assigned according to a worse behavior of the car during a slightly different crash or for occupants of different ages.

For example, if during the crash, the head is moved with its center of gravity outside the volume occupied by the airbag, the total point is reduced by one; same penalty is assigned if the correct functioning of the airbag is compromised by a fracture of the steering wheel or by interference with other objects. A penalty is also applied if during a side impact, a bigger intrusion of the A-pillar is noticed; in particular, no penalties will be applied if the intrusion is below 100mm while bigger intrusion of 200mm will create a two-point penalty.

One point is also subtracted if the structural integrity of the occupant's compartment is compromised; in particular, this occurs if after the crash the door hinges are broken and frame is not able to take door in position, the anti-intrusion beams are separated or if the doors cannot be open by hands.

Following this trend, a car which meets the minimum standards on safety imposed by the regulator is not considered for the assignment of any star. However, it is important to underline that a car which do not receive any star, or a low evaluation is safe but although it respects the safe standard foreseen by the low, its competitors are safer.

It also important to consider that the latest ratings are always most relevant; this because during years safety standards and equipment's changes and this also create an update of old ratings. For this reason, the Euro NCAP ratings has an expiring date which is imposed six years after the first evaluation; the expiration of a car does not mean it is changed in any way, but simply that standards and test are changed, and that evaluation became obsolete. During those six years of validity of the rating, each car manufacturers are asked to confirm the safety requirements of each vehicle in order to be sure that no modification has been introduced and if this occurs, manufacturers have to submit a detailed report of changes and have to demonstrate that those changes impact in minor way to the safety of the vehicle.

A substantial change in the stars rating has been made in 2016 when a two rating has been introduced for cars. The two evaluations refer to two different version of the vehicle; the first is the rating of the car equipped with the standard safety pack while the second one is the rating of the vehicle equipped with a safety pack available as add-on.

This second rating is not available for any vehicle but helps customer in the perfect choice of a car which meets with their needs.

CRASH TESTS

[10] [11]

There are a lot of crash test that are performed and that differ for the organization which regulate that test; there are those imposed by European directives, those for the insurance rating and the one performed by the Euro NCAP. Each one as different specification regarding the vehicle preparation, the dummies specification and more important the way the crush test is performed.

For what the Euro NCAP is concerned, we can divide the crash test in two group, the one considering the frontal impact and the other regarding the side impacts.

Before making this division, there are some common aspects among the two types of impacts regarding the vehicle preparation and the dummies settings.

For what concern the vehicle, there are some strict rules that has to be respect for a full reliability of the results. The loads are wisely positioned inside the car: the fuel tank is full at 90% of its capacity, a dummy weighting 80kg, which comprises both cables and instrumentation, is positioned inside the car, 20kg is positioned in the luggage compartment without folding the rear seats, the car weight has to be evenly distributed among front and rear as much as possible, the front seats are positioned in their middle position. Moreover, the vehicle’s battery has to be connected to the electrical system and the dashboard light indicating the airbag functioning as to be checked; if do not affect by the test, the luggage area has to be freed from any carpet and even from spare wheel and any tool.

Another important action is to mark some vehicle points like the upper half of driver and front passenger and the front half of the roof; moreover, the centerline of the vehicle is calculated and marked in the roof and the hood.

For what concern the procedure for the dummies, is important no people have access to the equipment used during the test; moreover, the dummy used has to be re-certified every three impact tests, if an injury criterion is passed the dummy needs a recertification and also if a part is broken, has to be replaced with a full certificate spare part.

Clothing too is regulated; in fact, dummy should be dressed in tight garments in stretch cotton with short sleeves and short trouser above the knees.

A very severe procedure has to be followed for dummies before using them in crash tests, in fact their temperature should be in the range of 19°C and 22°C measured not before than 10 minutes before the usage and moreover the dummies temperature has to be stabilized by putting in correct environment for at least 5 hours.

All the joints have to be set at the correct level of stiffness, in particular the screw witch acts on the constant friction screw should be adjusted in such a way the limbs are able to remain horizontal but fall down with the application of a minimum pression.

Dummies should be painted in some critical areas that should be checked after the crash. The paint should be placed near the test occurrence not to make it dry. In Table 3 [10] there is a summary of which areas are painted, which is the color and the size of the area to be painted.

AREA	**COLOUR**	**AREA SIZE**
Eyebrows (L/R)	Red	(25/2) *50 mm
Top of the Head (rear passengers only)	Blue	-
Nose	Green	25*40mm (down nose centerline)
Chin	Yellow	25*25mm (centerline)
Knee (L/R)	Red/Green	50*50mm (centerline)
Shoulder	Blue	100mm (square)
Rib (TOP)	Red	150mm (strip)
Rib (MID)	Yellow	150mm (strip)
Rib (BOTTOM)	Green	150mm (strip)
Abdomen	Red	50*50mm
Pelvis	Orange	50*100mm

Table 3: Dummies painted areas.

For what concern the instrumentation requirements, camera locations for 3D scan of the vehicle impacting and the test development, a division between frontal and side impact is necessary.

FRONTAL IMPACT

All the instruments used for measurements in crash tests should be calibrated before the test program and a re-calibration has to be performed after one year of test usage.

In Table 4 [10] there is a summary of the location of the instrument for data recording inside the dummies and what type of sensors is used so to understand what physical parameter is recorded; moreover, a data on minimum amplitude that the sensor is able to record is reported, in order to maintain a certain level of sensitivity channel amplitude class of order of magnitude higher than the minimum amplitude of the sensor have to be used. The last column provides the number of channels used for data recording used.

Its worth of note that three accelerometers are located also on the vehicle in precise locations that are on the left and right B-pillars and on driver seatbelt shoulder. Their location as to be located horizontally above a mounting plate which is placed horizontally on the pillar; everything with a tolerance of ±1°

LOCATION	**PARAMETER MEASURED**		**MINIMUM AMPLITUDE**	**N CHANNELS**
Head	Accelerations in x, y, z		250g	3
Neck	Forces	x, y	9 kN	2
		z	14 kN	1
	Moments in x, y, z		290 Nm	3
Chest	Accelerations in x, y, z		150g	3
	Deflection		100mm	1
Pelvis	Accelerations in x, y, z		150 g	3
Femurs (L/R)	Force in z		20 kN	2
Knees (L/R)	Displacements		19 mm	2
B-pillar (L/R)	Accelerations in x		150g	2
Driver seatbelt shoulder section	Force diagonal		16kN	1

Table 4: Frontal impact test instrumentation requirements

Is also important to position within a precise scheme, a series of high-speed cameras so to being able to film everything and to allow a perfect scan of what occurs to the car and the occupants during the impacts and in few seconds after. In Figure 18 [10] we have the scheme of location of the cameras. All those cameras are high speed cameras able to shoot more than 500fps while camera number 6 and 8 are normal camera able to capture more than 10fps.

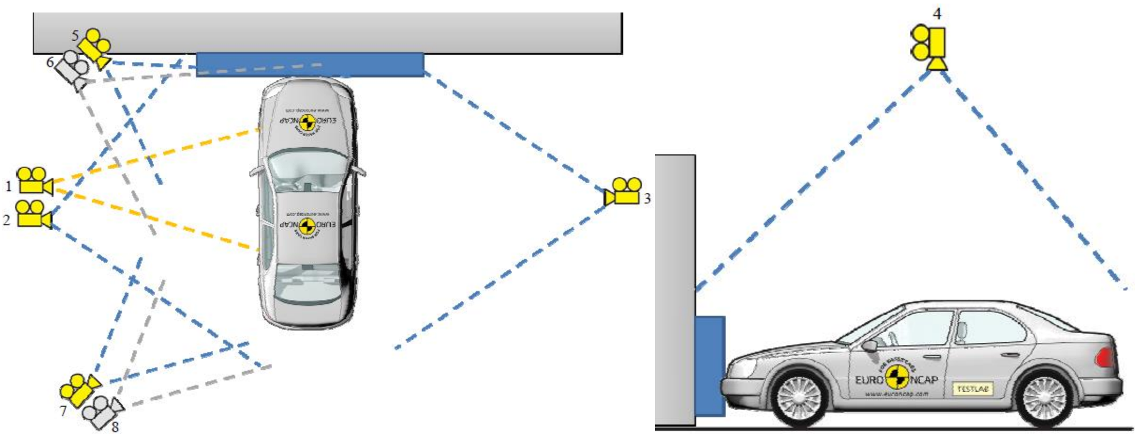

Figure 18: Frontal impact camera location scheme

For what concern the frontal impact, the test procedure is extremely strict and very highly regulated. First of all, the car is impacted against a fixed deformable barrier at 64 km/h on the driver side. The barrier, whose representation is reported in Figure 19, must respect some constraints in terms of measurements and maximum stress admissible; it has a honeycomb structure made in aluminum which has a maximum admissible stress of 0.342 MPa, its final part instead has a maximum stress of 1.711 MPa. It is 1000 mm wide and 540mm deep which is divided in 490mm for the honeycomb structure part and 90mm for the final part.

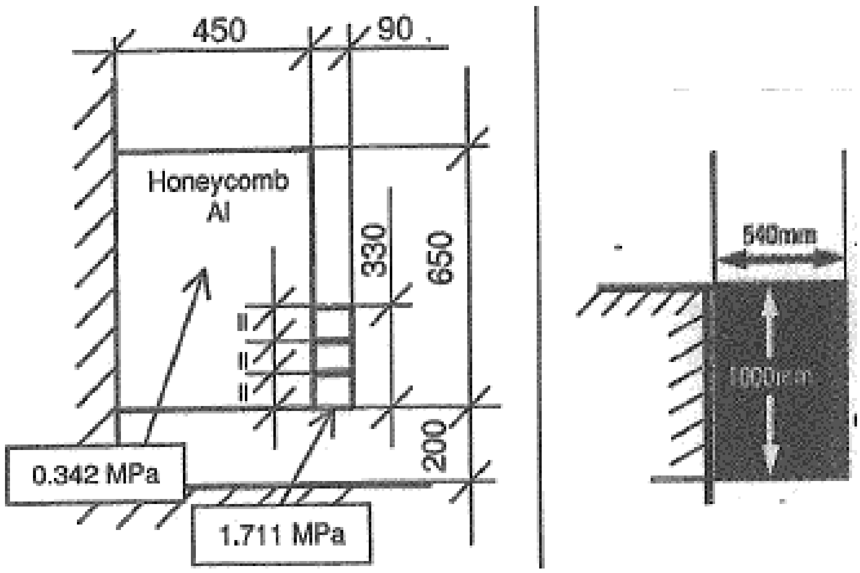

Figure 19: Frontal crash test deformable barrier

During the impact, the overlap between the car and the barrier has to be the 40% of the car lateral dimension. In Figure 20 we can see a picture which resume the test procedure.

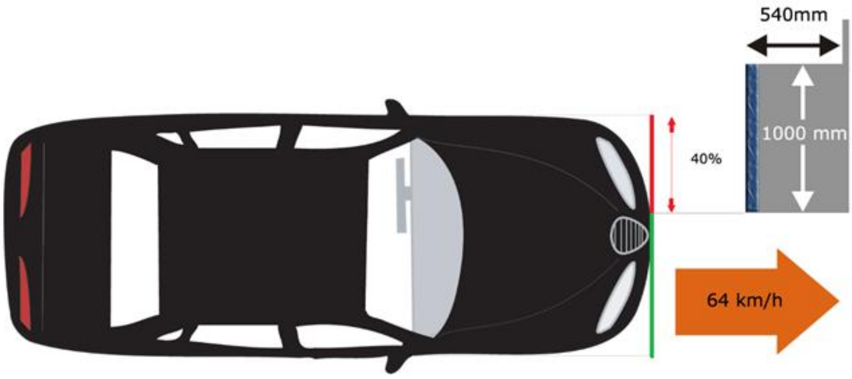

Figure 20: Frontal crash test

Inside the car are placed two dummies of 78+20kg. one dummy of 11+3 kg and one dummy of 15+3 kg, in the luggage zone a bag of 36kg is positioned while the fuel compartment is full at 90% with colored water.

The aim of the test is to understand which are the impact on occupants, understand the behavior of the restrain systems and the structural behavior of the car, check the ability of the fueling system to remain integral without dangerous losses that can become source of flame ignition. Furthermore, the ability of easily extract occupants from the vehicle is checked.

SIDE IMPACT

As for frontal impact, also in side impact a lot of instruments are required for measurements and recording of data; in table 5 [11] we can find a recap of all the needed sensors, the location where they are placed, the minimum amplitude of each sensor that has to be totally overlapped by the channel amplitude class chosen for each transducer and the number of channels needed for recording of data.

What we can immediately notice is that, recording instrumentation is not only placed inside dummies in various places (ex. head, shoulder, thorax, backplate femurs and others) but accelerometers are also placed on the vehicle and on trolley and barrier which is the moveable object which is used for impacting the car laterally.

In particular, precise prescriptions has been introduced for the location of the vehicle accelerometer, they are positioned on a mounting plate horizontally, with a tolerance of ±5°

LOCATION	PARAMETER MEASURED	MINIMUM AMPLITUDE	N CHANNELS
Head	Acceleration in x, y, z	250g	3
Shoulder	Forces in x, y, z	8kN	3
Thorax T1	Acceleration in x, y, z	200g	3
Thorax T12	Acceleration in y	200g	1
Ribs (U/M/L)	Acceleration in y	700g	3
	Deflection	90mm	3
Abdomen (U/M/L)	Forces in y	5kN	3
Backplate	Forces in x, y	5kN	4
	Moments in x, y	200Nm	
T12	Forces in x, y	5kN	4
	Moments in x, y	300Nm	
Pelvis	Force in y	20kN	1
Pubic Symphysis	Force in y	20kN	1
Femurs (L/R)	Forces in x, y, z	22kN	6
	Moments in x, y, z	350Nm	6
B-pillar	Acceleration in y	150g	1
Trolley center of G	Acceleration in y	150g	1

Table 5: Side impact test instrumentation requirements

Together with sensors, a precise scheme of cameras is located in order to scan perfectly what happens during a crash and in the moments after and during it.

The used cameras are mostly high-speed cameras which are able to capture more than 500fps while camera number 5 is a normal camera able to capture more than 10fps. In Figure 21 [11] we can see the representation of this camera.

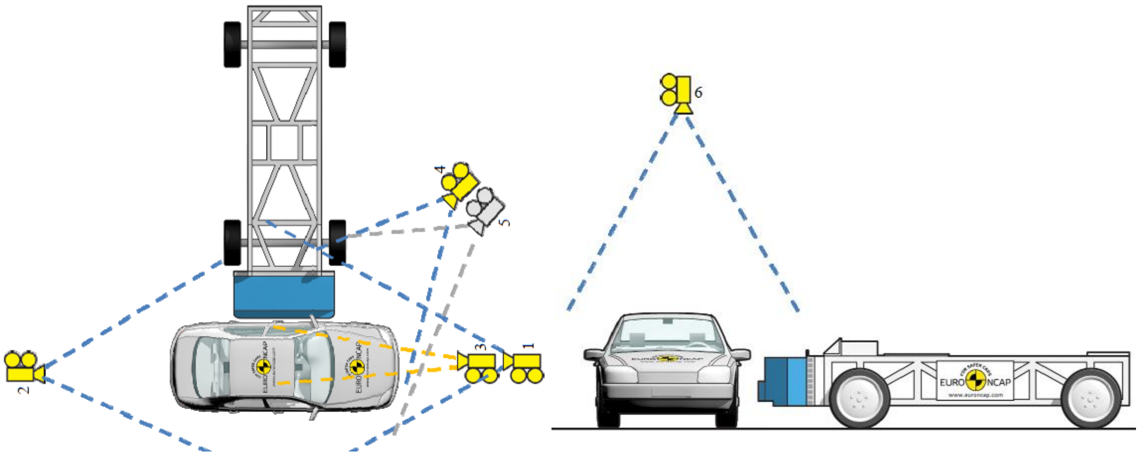

Figure 21: Side impact cameras location scheme

For what the procedure is concern, there are two types of side crashes: the barrier and the pole.

In the barrier side crash, a deformable moveable barrier weighting 950kg is impacting against a still vehicle at 50km/h on the driver side. The trolley and the barrier which composes a single unity have prescribed dimension to respect; the trolley has a distance between the axis of the two wheels of 3000mm and is 1500mm large, while the barrier posed on it is 1500 wide and 500mm long. Moreover, as we can see in Figure 22 the barrier which impact on vehicle is suspended from the ground of 300mm.

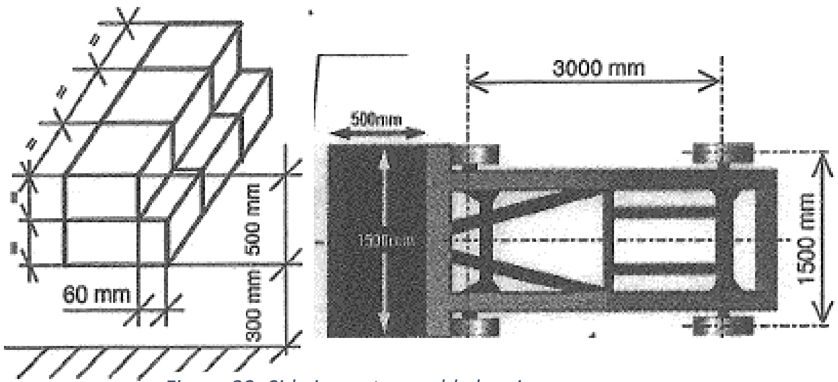

Figure 22: Side impact movable barrier

In this crash three dummies are located inside the car, the driver weighting 80kg and two passengers on the back: the one on impact side weights 11+3kg while the other 15+3kg. the fuel tank is filled at 90% of its capacity with colored water.

In Figure 23 we can see a picture which resume the crash test of a side impact with a barrier.

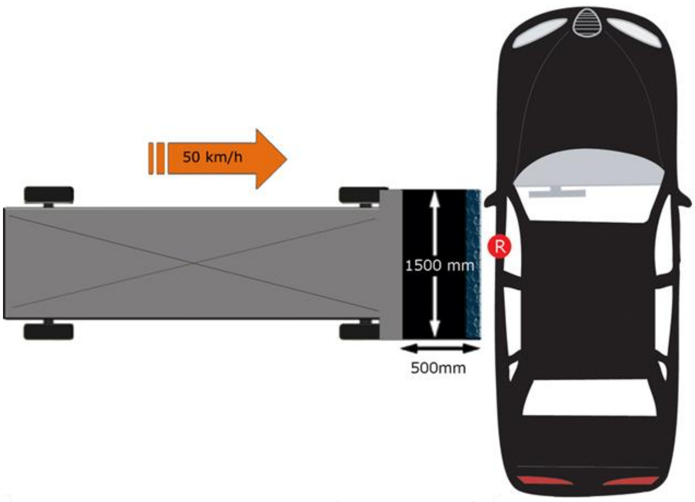

Figure 23: Side impact crash

The trolley axis is centered with R-point which corresponds to the driver's side hip valid for 95% of male adults.

This type of test is performed to understand which are the consequences on occupants of a side crash, to check the response of the restrain systems, to check that doors remained looked during impact to improve the structural integrity of the car and that the fueling systems have no losses due to the impact. Furthermore, the ability to extract passengers is controlled.

In the side pole crash, the car is located on a trolley which is moved at 29km/h against a fixed pole of 254mm diameter and whose center is aligned with the head of the driver. During this crash, just the driver dummy of 80kg is positioned in the car and in Figure 24 we can see a resume of the crash test.

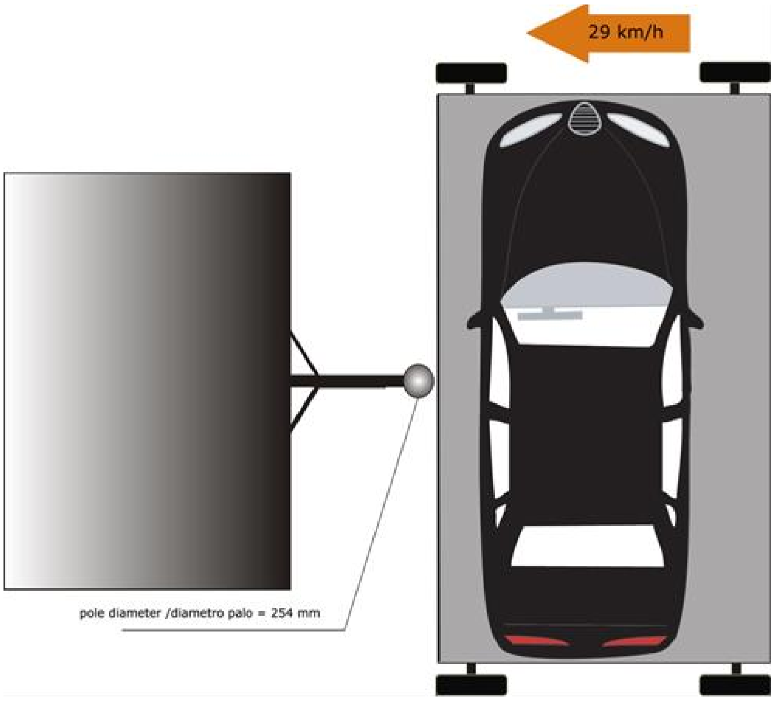

Figure 24: Side pole crash test

This type of crash test is performed to understand the consequence on occupants and the behavior of the lateral air bag systems.

ADOPTED CRITERIA FROM MANUFACTURERS TO COMPLY WITH EURONCAP TARGETS

As already explained, the Euro NCAP evaluate the performance of the car in keeping as high as possible the safety performance of occupants even more from the limits foreseen by the law. As they declare, the evaluation is given according to the safety of the occupants as well as the safety of other street occupants and also on the base of the safety equipment that the manufacturers offer to the final users.

for what concern the safety of the pedestrian, test to check their safety are performed, in particular car is impacted at 40km/h against dummies which represents pedestrian of any age. Thanks to this test some zones are highlighted on the hood where is most likely to occur the impact with the legs or with the head, as we can see in Figure 25.

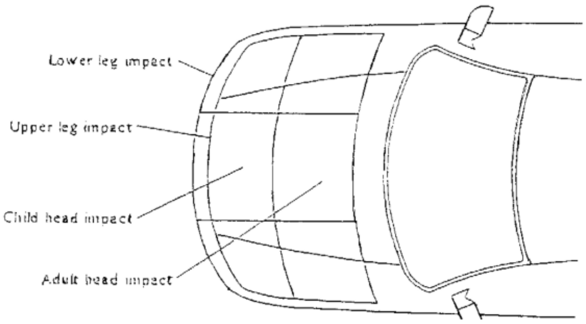

Figure 25:Hood impact zone

Moreover, thank to this test are identified some zones of the car that has to be designed respecting some angle of slope for prevent serious injuries to pedestrian during impact, as we can see in Figure 26

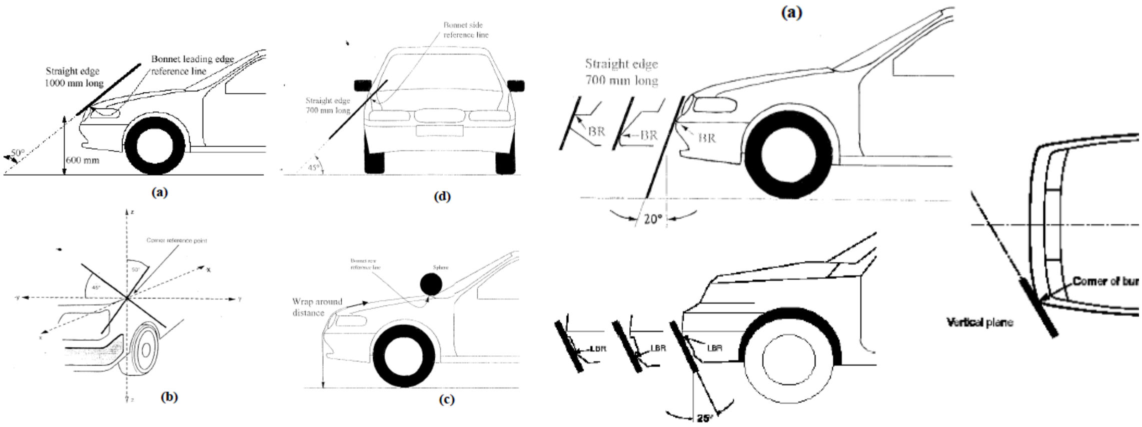

Figure 26: Car design angle for pedestrian safety

This argument will be treated in very detail in chapter 7 when it will be considered as a constraint for the design of the hood of a car; now its worth of say that these norms are not mandatory for the homologation of the vehicle and their application is a way for increasing the safety and also the number of stars in Euro NCAP rating.

Another way that helps manufacturers in obtaining a higher rates respect to the competitors is the safety assist equipment; in fact, those systems are not mandatory but the installation on the vehicle increase the safety of the trip for driver and passengers, increase the safety of pedestrians and other vehicle and if the test conducted have positive mark, it also increases the evaluation in stars of the car model.

Nowadays, Euro NCAP asses four systems and those are AEB, speed limiter, LKA and SBR.

Autonomous Emergency Braking (AEB): impact of a car with the back of a still car is the most common accident in Europe, those type of autonomous systems is capable of recognize a danger in front of the vehicle and if the driver is not able to brake in time, the systems autonomously action the brake and avoid the collision.

Those type of systems works with sensors like radars or lidars and most combines a braking action with an anticollision alert.

Initially AEBs where divided into slow and high-speed systems, from 2016 the difference is absent, so Euro NCAP test just the AEB car-to-car.

Autonomous Speed Limiter: the increase of driving speed above the limits is the causes of a lot of accident, for this reason there are some systems able to follow the limits imposed in a precise street where, for example, the traffic is too high or there are too many pedestrians.

Euro NCAP evaluate different function about the speed limiters like the information given to the driver respect to the traffic conditions, the alert to the driver in case of exceeding speed limits and the ability of the vehicle to force the driver command on the accelerator in order to avoid the exceeding of limits.

Lane Keeping Assist (LKA): in order to prevent the detaching of the vehicle from its own lane, vehicle equipped with those systems allow to the driver to always maintain the correct trajectory. In particular, an alert is sent to the driver in case of crossing the opposite lane and in some case, they also apply a small actuation to the steering systems in order to correct and restore the perfect trajectory.

To this class belongs also the Emergency Lane Keeping which provides a strong input to the steering system if they detect a critical situation.

Safety Belts Restrains (SBR): safety belt is the most helpful systems for the safety of systems and passengers during an impact. If not correctly wear, occupants are free to move and other safety equipment, like airbags, are not able to offer the correct level of protection without the belt cinematics.

The adoption of those systems, mostly not mandatory by the law for the homologation, is well seen by Euro NCAP which rewards manufacturers with a higher star rating.

Finally, is important to point out that the stars rating is not assigned to the manufacturers directly but to the specific vehicle model which is evaluated. Anyway, having a higher rating is, for the manufacturers, source of pride and is used as advertisement against competitors for selling more vehicle which are considered safer. For this reason, nowadays we have always more car models which offer those type of systems to the customer even if they are not mandatory by the law.

THE BODY IN WHITE

In this section of my thesis, I would like to introduce a topic related to the structure of the car that is the BIW. Its design is strongly influenced from the segmentation and all the regulation presented so far and is the perfect introduction to the project that I develop in Magna Steyr Italia and which I will present in the last chapter of my work.

For this reason, I will talk about the definition of BIW, which are the different type of BIW which exists, which are the most used materials and technology for producing and assembly.

Finally, I will talk about the modularity of the platform among several different project; this is a very crucial point for car makers for developing new projects controlling the cost by using a platform which has been already optimized from the engineering point of view and so would be a waste of money, time, and resources to use it just for a single project.

BIW DEFINITION

A body in white, abbreviated with the acronym BIW, is a component made by the assembly of the frame and the panels.

To the BIW, many components are then fitted and those are named "moveable parts" which includes the doors, the hood, and the tail gate; all the external components like the bumper, the windscreen, the lamps, and the mirrors; and all the internal trim which includes all the instrumental panels, the seats and so on.

In Figure 27 we can have a clear understand of the BIW and the moveable parts which are detached from it.

Figure 27: BIW plus moveable parts

The main aspect and functionalities that the design of a BIW has to reach are several and includes different areas; for the aesthetical point of view in which it has to provide a nice looking; to the important structural and safety functionalities according to which the BIW has to support the weight of the component which are installed on it and of passengers as well as protect them from any injury; passing for the ergonomic goal for the wellness of the occupants without forgetting the insulation aspect according to which the insulation of the internal part of the vehicle respect to noise, vibration and heat generated by components has to granted.

BIW CONFIGURATIONS

Several configurations of BIW can be identified according to the underbody configuration. Those coming out are solutions which more or less can fit perfectly with all the functionalities that a BIW has to respect seen so far. We can identify four different configurations: [12]

UNIBODY

Is characterized by the fact that the chassis cannot be detached from the upper body; the consequence of this design is that all the mechanical parts are directly connected to the frame.

The advantages brought by this configuration are the lower weight they can achieve but at the same time a big disadvantage is the low dimensional precision for the attachment points of the suspension.

BODY ON FRAME

Second configuration in which the chassis is connected to the upper body but with bolts; this solution offers big advantages like the possibility of using same chassis for several upper bodies, and also in terms of simplification of the assembly process of the chassis.

For its modularity, this solution is often adopted by manufacturers for duty vehicles, vans, and SUVs.

The main disadvantage is the weight which results higher respect to the previous one.

BODY WITH ACCESSORY SUBFRAMES

This third configuration consist of a certain number of subgroups which provides supporting function for powertrain system or suspension systems. Those subgroups can be connected to the body thanks to rigid bushings or elastic ones.

The main advantage is that having a damping device between two elements helps in having a more efficient noise insulation while increase the overall weight of the system.

DUAL FRAME BODY

The last configuration that we can highlight is the one in which the body and the chassis are two separate elements and then they are connected through elastin bushes. In this configuration, all the structural functions are confined in the chassis focusing on front and rear crash absorption and to torsional stiffness and resistance stresses induced by suspension and powertrain.

Despite the total weight is still a disadvantage, in this configuration more than the others, this is counterbalance by the concentration of the weight in the lower part with a reduction of the upper body weight.

BIW ASSEMBLY, MATERIALS

ASSEMBLY

We will analyze the BIW final assembly as a group of several subcomponents that can be separately studied for their complexity and for the number of parts of which they are made.

The lower part of the body is called underbody and is considered the most important assembly which composes the BIW for its structural functions and for the evolutions that the parts that compose this subassembly have undergoes over the year to adapt to better performance requests.

In Figure 28 [12], we can see an exploded view of all the components of the underbody. The main component is the frame (in picture signed with number 1), which support all the other components as well as members connected to the bodyside. As we can see it support the front (number 2) and the rear floor that is divided in front and rear part itself (number 4 and 5); it support also the cross member (number 3) which is a structural element for passengers seat supports and other elements like strut tower reinforcement (9R/L), the dash top panel (6), the inner body sides (8R/L), the back panel (11) the upper boxing rails (10R/L) and the rocker panels (7R/L)

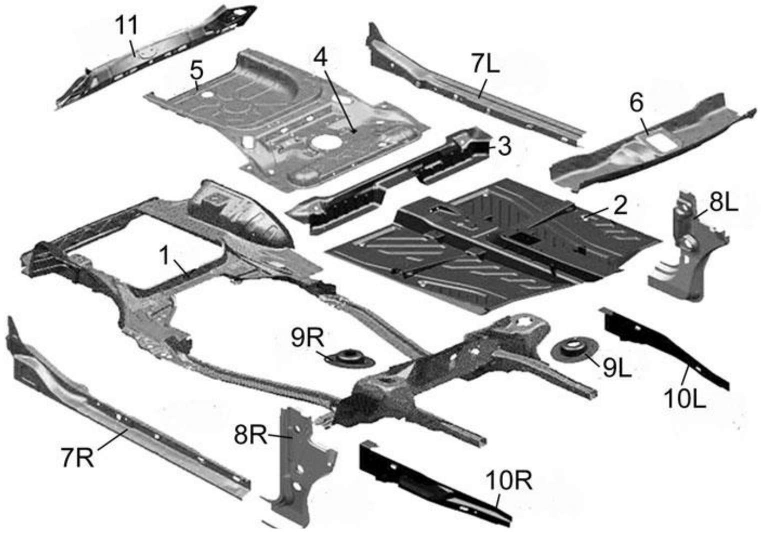

Figure 28:Under Body Assembly

A focus is made to the underbody frame in order to understand the element that composes this important element; in Figure 29 [12], we can notice that it is divided in three main groups.

The first one (highlighted with number 1) is the front subframe. It is an important element for the huge number of functions it performs; it provides the attachments for the shock absorber, supports for powertrain reinforcement, it is designed in such a way it is able to support the high load coming from a front crash and much more. The left and the right rails are then connected by a cross member whose function is to distribute the load of a crash to the floor tunnel.

The second element (number 2) is the rear subframe which provide structural function for rear impact, it provides connection for rear suspension, it allocates space for trunk support and much more.

The two subframes are then connected with the underbody rails (3R/L) resulting in the underbody frame.

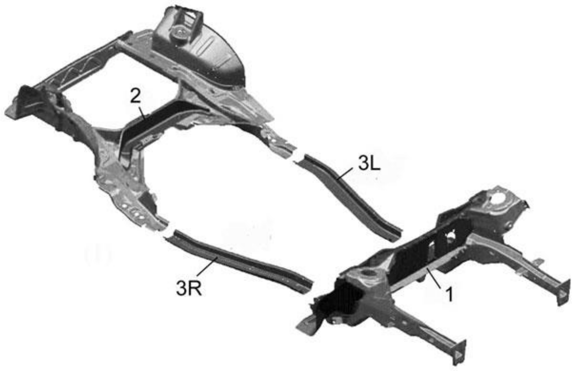

Figure 29:Underbody frame exploded view.

The BIW final assembly is completed, as reported in Figure 30, by joining the underbody assembly seen so far together with the side panels (number 4 and 5) which are most affected by styling constrains, the top part of the hood and the header (number 6 and 7), the frame of the roof (8) and the two upper rail (2 and 3) which has structural functions in terms of stiffness absorption and front crash support.

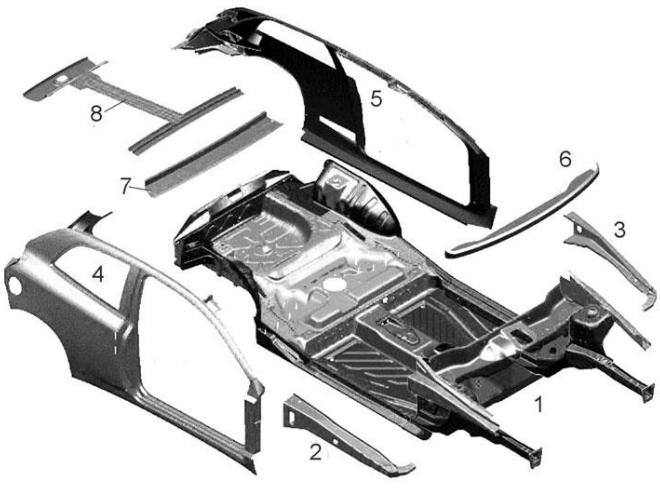

Figure 30:BIW assembly

MATERIALS

The choice of the material is very important and is related to an accurate analysis on the mechanical and chemical properties as well as on the characteristic curves that can indicate critical region for the material.

Taking into consideration steel sheets, the main techniques for their deformations are the stretching, which is an isotropic elongation of fibers; and drawing, which instead consists in fibers that elongate in one direction and shrink in the other.

To analyze the performance of the steel sheets, we have to focus on the study of two properties which can be a huge discrimination factor in the choice of the right material.

The first property is the formability which is evaluated after the computation of traction and drawing test in which the main parameters measured are loads applied and elongation and shrink to which the material specimen undergoes up to its completely breakage. The important parameters are the anisotropy index which is related to the drawability and the hardening coefficient which is related to the plastic deformation induced in the specimen during the test.

After the test has been performed, a breaking risk is assessed. This consists of the risk of breaking a piece during a formation process and it consider the two principal direction of formation (e1 and e2). The risk evaluated is inserted in a graph named forming limit curve (FLC) reported in Figure 31 [12]. From the FLC graph we can notice a limit curve below which we are in the risk-free zone and above which we are in the breaking risk zone.

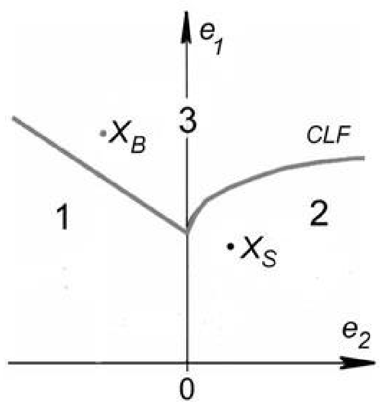

Figure 31: CLF graph

The second property to be evaluated is the spring back which consist in the ability of the materials fiber that are not yet plastically deformed, to return to their original shape.

Once made this introduction on what has to be analyzed before choosing the BIW material, we can focus on the most used materials:

- Steel Sheet. They are mainly iron alloy sheet with a low percentage of carbon inside; they have a deep drawing capacity and an elongation before breakage of about 40%.

this main advantage is followed by the fact that after formation process the surface appear smooth and doesn't need any post finishing treatment. Moreover, has a quite large field of option of joining technologies that can be applied (spot and wire welding) as well as a 180° bending without any problem.

The main drawback is the weight, the indentation deformation induced when the thickness of the sheet is lower than 0,80m, and the corrosion iron undergoes but this problem has been solved with zinc coating or galvanization.

- Aluminum Sheet. The main important advantage respect to iron sheet is the lower specific mass that helps in reducing the overall part weight.

  The difference between the two materials is evaluated in terms of bending stiffness, for this reason, in practice, a sheet of 1.2mm of aluminum is used to replace a 0.8m thick steel sheet; this implies a weight saving of 45%.

  Regarding the formability of aluminum sheets, they have a worse behavior respect to the steel sheet also considering the joining technologies. In fact, welding for aluminum is more difficult since it needs an inert environment and for this reason rivets are used when possible; while glue is used when style constraints impose a perfect external surface.

- Aluminum Die Casting. It is used in some application when having a single aluminum piece is beneficial respect having more sheets joined together. The lowest thickness of a die cast piece cannot be lower than 2.5mm but in any case, the part is still lighter than the corresponding part in steel.

- Aluminum Extrusion. They are used for linear or curved pieces that needs a constant cross section. Those type of pieces have beneficial characteristics for bending facing.

MODULAR UNDER-BODY PLATFORM

The concept of having a modular under body platform has been an improvement developed that helps in meeting the various customer requirements as well as the manufacturer requirements too of shorten the product cycles and reducing costs.

For this reason, a lot of car company has changed their production method in order to switch from a platform-based production method up to a module-based method that helps in having the possibility of using a single module for more vehicles.

This has been implemented in vehicle platform as it represents almost half of the cost that a company has to face for the whole project development; as we can notice in Figure 31, the platform is divided in modules and those are combined together and used for a specific type of vehicle (MPV, SUV, sedan)

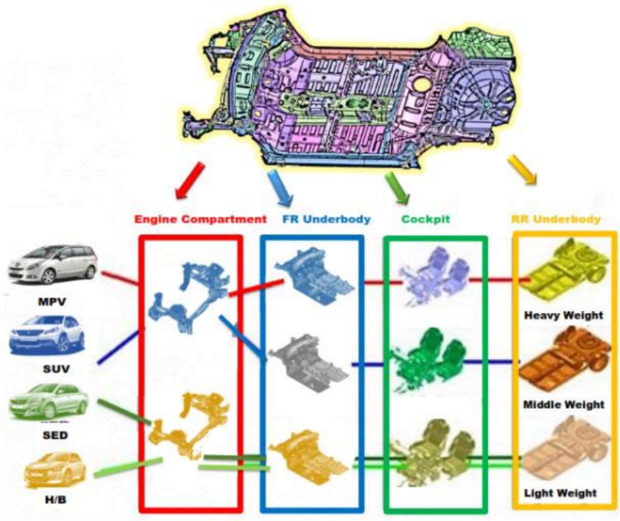

Figure 32: Vehicle under-body platform modules

The great advantage of having a high level of modularity can be seen better in Figure 33, where we can appreciate the part of the vehicle that remains common and the part of the vehicle that are inter-changed in order to achieve different segments vehicles.

As we can notice, by keeping unchanged the wheelbase, and so the center module of the under-body platform, and modifying the rear part and the front we can achieve a sedan or a SUV starting from a station wagon configuration.

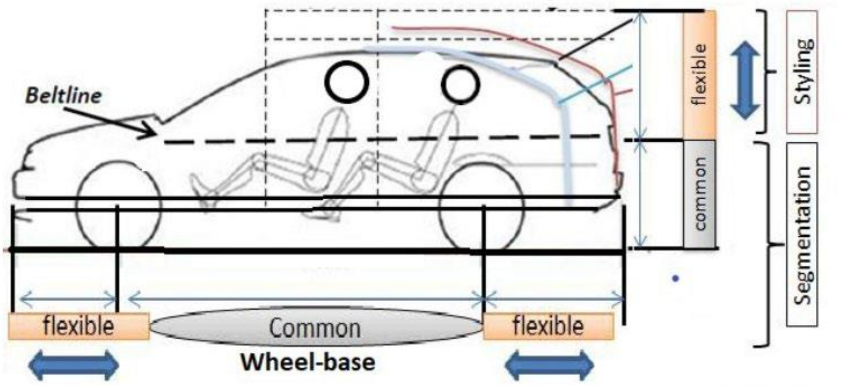

Figure 33:Vehicle modularity

The application of the modular underbody platforms meets the need of the hybrid and electric systems that nowadays are becoming protagonists on the market.

The Advantages brought by these solutions are:

- Flexibility in manufacturing processes, since the final piece is composed in modules that can be assembled according to the need, in a single line both the platform for a combustion engine as well as for the electric version can be assembled.

- Costs assessed for the development of the pieces are lower since all the costs involved for the design of the jig and tools for assembly process are designed to be compatible with more vehicles.
- A great diversity of product can be manufactured since the cost of the origin platform has been already paid.

Obviously, also a series of disadvantages are produced by this configuration but are all related to the perception of the brand from the customer point of view as well as on the cost of conflicting modifications made on the platform.

ALUMINUM PASSENGER CARS

The aim of this thesis is to design the hood skeleton of a luxury vehicle both for a production process made in aluminum and carbon.

For this reason, in this section I want to go more in deep trough aluminum characteristics, and I want to highlight the properties that this material has as well as the production processes and the joining processes.

MATERIAL PROPERTIES

Aluminum is a non-ferrous material, which means a group of metals that do not based on iron. The non-ferrous materials obviously don't match the strength characteristics of the steels, but they can show a good corrosion resistance as well as a great strength to weight ratio which means that they are able to show a good mechanical capability despite his relative low weight.

In particular Aluminum, has good properties in terms of high electrical and thermal conductivity as well it shows an excellent resistance to corrosion thanks to a thin and hard film on the surface which protects the material.

Moreover, it shows a good ductility, and this is a good point if we consider the formability which is important to create the perfect shape for having a structure with good mechanical properties and that can be adapted to the style guidelines that has to be followed when design a hood skeleton or any other component of a vehicle.

It has to be noted that, at his pure state, aluminum has low strength; its properties are improved by inserting it in alloys and computing a heat-treating process. The aluminum alloys are categorized according to the material present and each one is associated to a digit system for easy recognition. We can have two types of Al-alloys, the first are the cast alloys which are produced by casting process and the second are the wrought alloys produced by mechanical processes.

In Table 6, there is a resume on how the Al-alloys are divided and how they are composed.

As we can notice, to every alloy a system of four digit is associated for what the wrought alloys is concerned and a system of five digit is associated for the casting alloys. To every cod, a precise percentage of a specific material is associated, and this create a specific alloy with different mechanical properties.

An important aspect to consider is that, according to the element present in the alloy and to the thermal treatment that they eventually undergo, they can be weldable or non-weldable alloys. This distinction is caused by the crack sensitivity caused by the main alloying element.

WROUGHT Al-alloys	Non-heat treatable alloys	1xxx	none
		3xxx	Mn
		4xxx	Si
		5xxx	Mg
	Heat treatable alloys	2xxx	Cu
		6xxx	Mg + Si
		7xxx	Zn
		8xxx	other
CASTING Al-alloys		1xxx0	none
		2xxx0	Cu
		4xxx0	Si
		5xxx0	Mg
		7xxx0	Zn
		8xxx0	Sn
		9xxx0	Master Alloys

Table 6: Al-alloys

According to the project I was assigned to, the Al-alloy used for the production of the skeleton of the hood is the series 6xxx and in particular the 6014 T4. This is a particular type of Al-alloy which achieve its characteristics thanks to the T4 process which is a quench process with a naturally aged process.

This alloy shows a low density which means a great reduction in the vehicle weight; it has an excellent absorption characteristic, as well as good specific strength and rigidity; for this reason, it is used in structural part of the vehicle because it is able to withstand high impacts and high vibrations.

In particular, compared ot the other alloys of the same series, it shows a greater elongation at breakage, higher mechanical properties under high working temperature, a lower density as well as a lower price.

In Table 7, there is a recap of the main mechanical characteristics of the choosen material.

	Aluminum 6014 T4
Density [kg/m^3]	2700
Elastic Modulus [Gpa]	69
Yield Tensile Strength [MPa]	80
Ultimate Tensile Strength [MPa]	160
Maximum Elongation [%]	17

Table 7: Aluminum 6014 T4 mechanical properties

PRODUCTION PROCESS

The metal forming process [13] includes a group of production processes that are based on the induction of a plastic deformation in the aluminum pieces which aims to change the final shape. The plastic deformation is induced by some dies.

To be able to successfully form the aluminum workpiece, it is important that the material has some properties which improves the forming process; those are the low yield strength and the high ductility. Those properties can be increased thanks to the working temperature; in fact, as the temperature is raised up, ductility follow that trend while the yield strength is reduced and that is positive.

Following that principle, we can have three forming processes according to the temperature at which they are performed: cold, worm and hot working.

The processes can be classified in two groups that are the bulk deformation and the sheet metal working; each group is composed by a series of specific processes.

For what concern the bulk deformation we have four possible processes which are the rolling processes which is a compressive deformation aimed to reduce the thickness of a plate; the forging process which is based on a compressive deformation between two dies to impress the dies shape on the metal piece; the extrusion process in which the metal piece is forced through a hole to reduce its diameter and finally the drawing process which instead is pulled through a hole. In Figure 34 [13] we can have a clear representation of those processes.

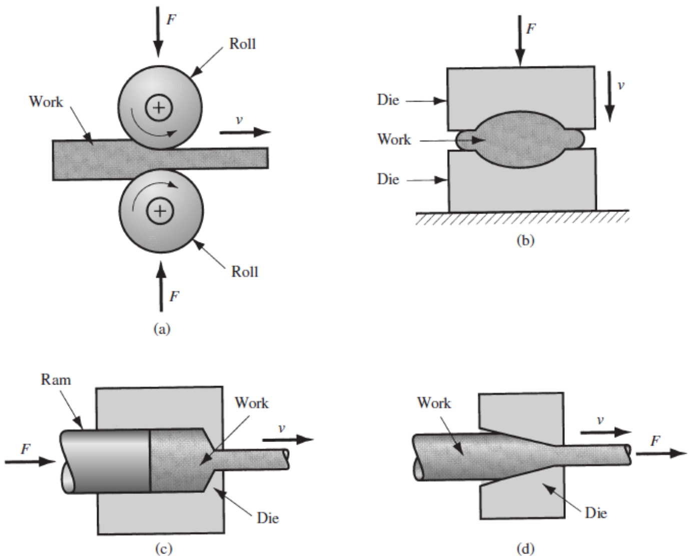

Figure 34: Rolling (a), Forging (b), Extrusion (c) and Drawing Processes (d)

For the Sheet metal working instead, is composed by processes which includes forming and cutting operations made on metal sheets; a part produced with this method is called stamping.

This type of processes is generally performed as cold working and is made thanks to a set of tools which are the punch which pushes the metal sheets against the die which give the final shape to the piece. Inside this group we can have bending and drawing processes as well as the shearing process which is more a cutting than a forming process. In Figure 35 [13] we can have a representation of the three processes.

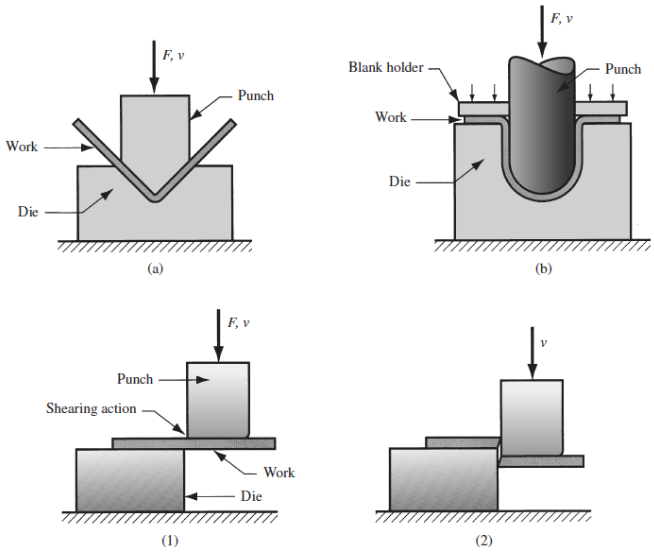

Figure 35: Bending Process (a), Drawing Process (b) and Shearing Process

In Figure 35 [13] we have a rapid overview on the metal forming processes explained so far.

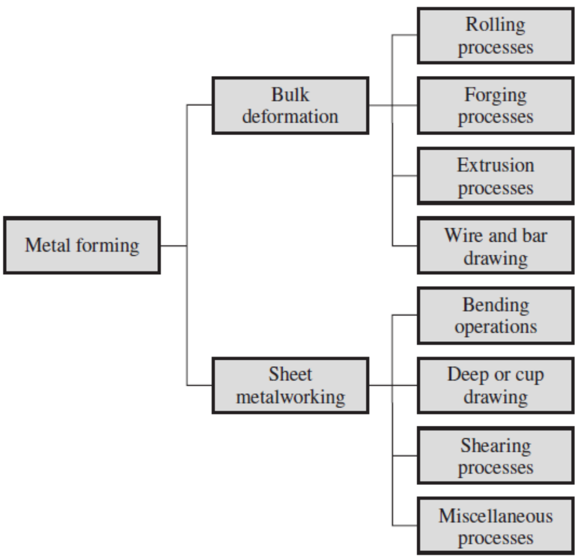

Figure 36: Metal Forming Classification

In the project I was assigned to, and generally in the automotive sector, the main process used for the production of all the panels, skeleton and structures is the sheet metal forming. The process starts with an aluminum sheet which is inserted between the punch and the dies to obtain the final desired shape.

MECHANICAL CHARACTERISTIC OF MATERIAL IN METAL FORMING

[13] A detailed analysis of the material during the forming process can be obtained from the stress-strain curve which describe the evolution of these two characteristics; the graph is basically divided into two regions, the elastic deformation area in which all the deformation induced in the material can be recovered since the yield strength is not overcome and the plastic deformation region which instead is characterized by a permanent deformation of the material and a strain hardening. The relation which describes the characteristic of the material in the plastic region is: $\sigma = K\varepsilon^n$; where σ and ε are respectively the stress and the strain; K is the strength coefficient and n is the strain hardening exponent.

The relation of the quantities explained so far is described by the flow curve, which indicates the flow stress of the material. Every time we induce a deformation in the material, it undergoes to a strain hardening, as already said, which consist in the increasing of the yield threshold to induce a further plastic deformation; this means that the stress that we need to continue to deform plastically the material has to increase. The flow stress is the instantaneous value of stress that has to be applied to continue deforming the material. This quantity can be expressed through the equation: $Y_f = K\varepsilon^n$; where Y_f is the flow stress.

In particular, the instantaneous flow stress can be used to evaluate the process and its occurrence but to better analyzing the process, the average flow stress is more useful. It describes the stress-strain curve from the beginning to the maximum value of the strain during the process. In Figure 37 [13] there is a representation of the stress-strain curve with the flow stress indication.

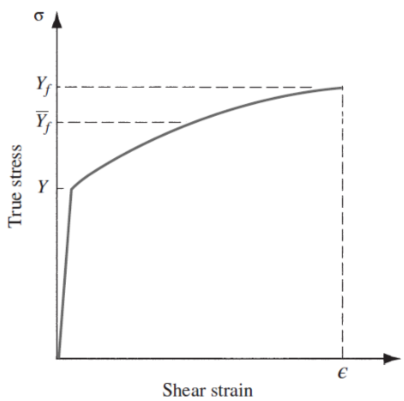

Figure 37: Stress-Strain curve

An important parameter which influences the curve represented above, is the operation temperature of the forming process; in fact, the parameter K and n seen in the previous formulas are directly influence by the temperature and as a consequence, both strength and strain hardening are reduced with the increasing of the temperature. Other properties that change with the temperature are the ductility which allow a greater plastic deformation and the forces to be used in the process that is sensibly reduced. We can identify three ranges of temperature used for metal forming:

- Cold working. The advantages of this process are related to the greater accuracy, the better surface finishing obtained at the end of the process, the higher hardness of the final product that undergoes to the strain hardening as well as the grain flow which ensures to the final piece bigger directional properties. Next to what just said, there are some disadvantages in performing the process at room temperature and are related in the bigger forces and power needed to execute it and in the low ductility which limits the maximum formability reachable.
- Warm working. The temperature used for this process is greater than the room temperature but lower than the recrystallization [12]temperature, and is nearly 0.3Tm which is the melting temperature. According to the higher temperature, the plastic deformation is favored and for this reason the greatest advantages are the reduction of the forces and power induced in the process as well as the greater range of more complicated shape that can be performed respect the cold working.
- Hot working. The temperature is even higher, between 0.5 and 0.75 Tm; this produces biggest advantages which consist in the high plastic deformation that can be induced in the material, the lower force involved in the process and the high range of complicate shapes that can be performed. This process involves also big disadvantages which consists in the low dimensional accuracy as well as surface finish, the surface oxidation, and the high thermal energy that the process need to increase the temperature up to the correct working range.

Considering a metal which is processed at elevated temperature, it should behave as perfect plastic material since it has the exponent n=0; this means that if we reach the correct stress, the material has to continuously flow keeping the same level of flow stress. The phenomenon described is named strain rate sensitivity and is related to the effect of the strain rate on the strength property of the material.

[12] Recrystallization = process by which the original grains of the material are substituted by new grains that nucleate until completely substitute the original ones and are considered free of defects.

In Figure 38 we can have a graph showing the characteristic of the flow stress versus the strain rate with respect of the working temperature.

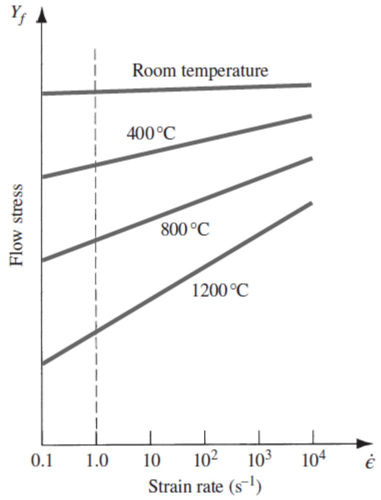

Figure 38: Flow Stress vs Strain Rate

An important aspect to keep under control, especially during the cold working, is the friction that arises during the process due to the relative motion and the high pressure between the material and the working tool. The consequence induced by the friction are the retard in the metal flow, the increasing of the forces involved and the early wear of the materials.

Moreover, if the friction of the material becomes high enough, the sticking phenomenon may occur, which consist in the completely adherence of the two surfaces and this prevents the part to slide in the dies. For this reason, lubricants are applied between the surfaces of the metal and the one of the dies; those allow the reduction of the forces, the tool wear and prevent the sticking.

JOINING PROCESS

The joining method has become a really important topic throughout the automotive sector, especially because it is introduced in the bigger focus of having a lightweight vehicle with good mechanical properties.

The performance of the joint method depends on several aspect such as the method chosen, the quality both of the method and of the surface to be joined. Moreover, the method to be chosen is not arbitrary but it depends on the limitation of the two materials to be joined; in fact, the compatibility of the two material is important in order to understand if they are weldable or has to be joined with other solutions.

In Particular, we can identify three solutions that are commonly used in the automotive sector: the liquid phase welding, the mechanical joining, and the adhesive bonding [14].

LIQUID PHASE WELDING

It consists in the local heating of the materials to be joined; in that area, a liquid phase is induced in the pieces due to the high thermal energy. This is transformed in solid bonding thanks to the application of a localized pressure under which the liquid phase solidifies. Two example that are widespread used in the automotive industry are the spot and arc welding.

SPOT WELDING [14]

This is the most used method in the automotive sector due to its low cost, robustness in the welding process and also due to its high process speed thanks to the high automation level.

The joint is made thanks to an electric current that passes through two electrodes which pushes against the two sheets to be joined; this creates a localized heat able to melt a small portion of material called nugget; the pressure developed helps in keeping together the two sheets for the entire process. In Figure 39 we can appreciate a spot-welding scheme.

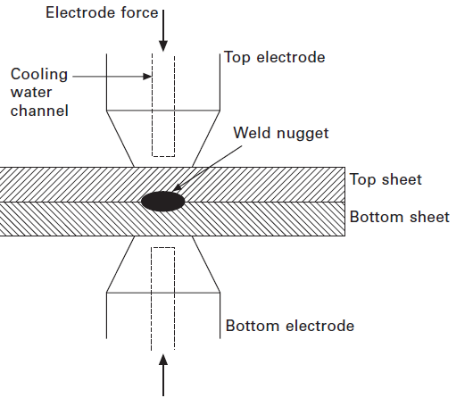

Figure 39: Spot Welding Scheme

It is clear, at this point, that the quality of the spot welding depends on the weld nugget, and in order to perfectly control it we have to perfectly tune the weld current, the welding time, the force of the electrodes and the hold time.

As can be easily understood, the nugget diameter will increase with the increasing of the parameters mentioned above. In Figure 40.a we can appreciate the evolution of the diameter of the nuggets with the current, while in 40.b we can appreciate the perfect welding range as function of the welding time and current.

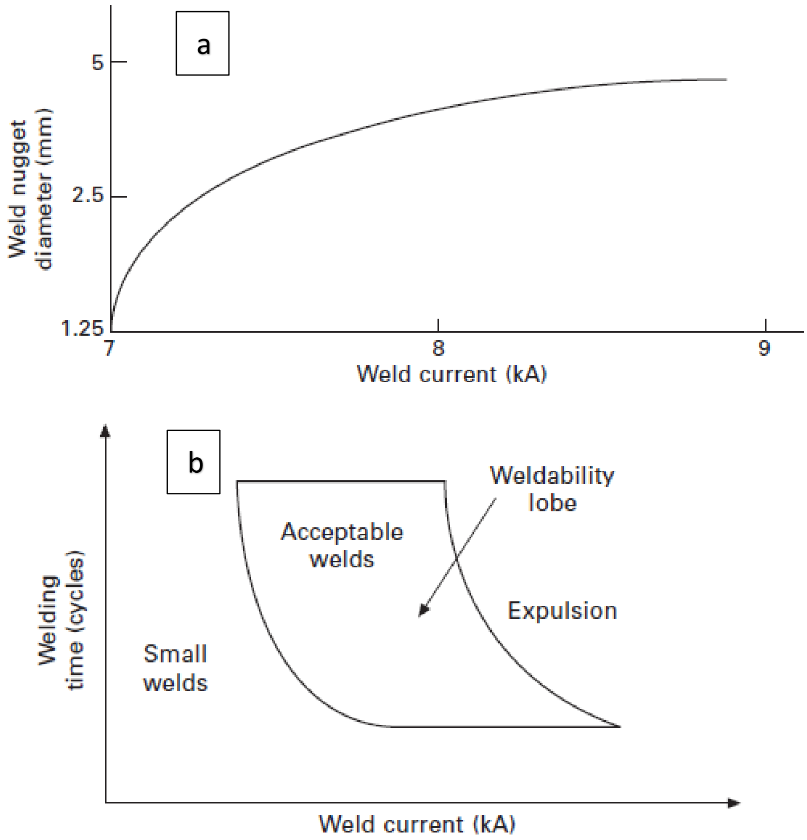

Figure 40: Spot Welding Characteristics

Particularly attention has to be paid on this technology applied to aluminum, since it is more difficult compared to the other materials and this is due to its mechanical properties.

First of all, aluminum has low electric resistance, this means that the weld current has to be two to three times higher respect steels and for this they need larger machines; then, due to the high current, it needs almost a quarter of the welding time used for steels and this caused by its high thermal conductivity and the low difference in temperature between softening and melting of aluminum.

Another difficulty is represented by the oxidation layer that is formed on the outer surface of the aluminum working piece; this has a melting point much higher than the pure material.

Great attention has to be paid in the preparation of the working piece before welding. This because the lubricant oil used during the forming process has to be removed in order not to alter the final resistance of the welding.

Finally, among the different Al-alloys series, the 6xxx series needs higher weld current than 5xxx due to the bulk resistivity.

ARC WELDING [14]

The principle is the same as before, but now the heat needed to produce the melting of the material is produced by an electric arc formed between the part and the electrode itself. The electrode can be a consumable rod, meaning that it conducts current as well as it melts in order to produce a filler function; or can be non-consumable, meaning it simply conduce electricity.

The electrodes are able to produce a really high temperature which is able to melt the material and as the electrodes is moved away, the liquid pool solidify, and a solid bond is made. In Figure 41 we can appreciate a representation of the arc welding.

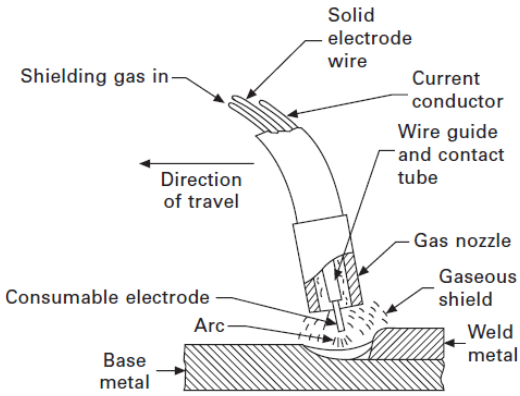

Figure 41: Arc Welding Scheme

It is important to note that the liquid metal can reacts with the air reducing the solidity of the joint; for this reason, in the welded area a shield is created by spring inert gas.

One more time, the application of this technology to the aluminum is more difficult respect to the steel; first of all, the problem is related to the oxide layer that has a temperature of melting which is far higher than the one of the pure aluminums. Moreover, the oxide layer tends to easily absorb the hydrogen present in the air causing porosity in the welding and a weak bonding.

For what concern the Al-alloys mostly adopted in the automotive sector, the 5xxx series have higher weldability respect to the 6xxx that has a lower weldable area and needs a filler material to prevent cracks coming from shrinkage of the material.

MECHANICAL JOINING

[14]The most used mechanical joining procedure in the automotive industry is the self-pierce riveting; it is a cold forming operation which consist in joining two or more sheets together with a tubular rivet that then is deformed in the flanks into the bottom sheet in order to deform the parts and creating a mechanical interlock. In Figure 42 [14] we can see a representation of the self-pierce riveting procedure.

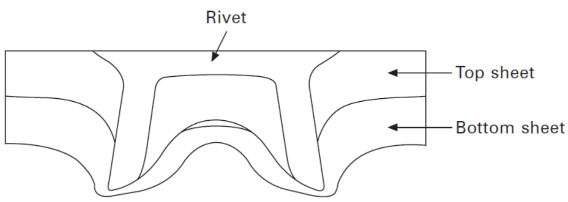

Figure 42: Self-Pierce Riveting scheme

This technology is very interesting since it doesn't need any pre-drilling of holes and as a consequence, it doesn't need no alienation of holes. Moreover, it allows positively joining two materials that are completely different or that have poor weldability characteristic.

Considering aluminum sheets, the maximum thickness that can be joined thanks to this method is 10mm; and for obtaining the maximum performance from the rivets, some good practices have to be respected, for example the rivets have to be inserted from the sheet with the lowest thickness to the bigger one and also from the harder to the softer material.

The process through which this technology is applied is composed by four steps that are the clamping of the two sheets in order to keep them perfectly in position, the piercing of the rivet in the sheets, the flaring that consist in the deformation of the rivet flanks and finally the releasing. In Figure 43 [14] there is a representation of the four phases.

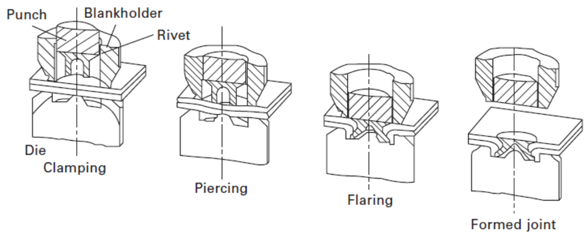

Figure 43: Self-Piercing riveting procedure

For controlling the joint, we have to control the rivet design and parameter as well as its length and its head style; moreover, it is important to control the die shape and its diameter. Another important parameter is the material that has to be high strength steel with coated surface to ensure corrosion protection, this last characteristic is really important for aluminum sheets.

According to the resistance of the joint itself, the rivets are less resistant respect to spot welding, although the fatigue strength is far high respect to those of the welding; in fact, at one million of cycles, the fatigue strength of rivets in aluminum sheet is from 25 to 100 percent higher respect spot welding. Other advantages are related to the fact that it is possible to join dissimilar materials, it is possible to have a faster, less energy requirement and safer cycle with respect to the spot welding one.

Disadvantages, instead, are related to the fact that for aesthetical purposes the rivets cannot be used on external panel, they require double access from both sides of the sheets to be joined and also, they require high force for computing the forming process and this can also cause joint distortion.

ADHESIVE BONDING

[13]The adhesive is used in a wide range of application both for bond and seal dissimilar materials. The adhesive bonding consists of the application of a filler material in order

to hold together two surfaces; among the categories, the structural bonding has great interests since are able to provide strong juncture.

The positively joint of the adhesive bonding passes through the curing process with which we identify that portion of the process in which the adhesive change its status from liquid to solid thanks to the usage of a catalyst or simply by heat.

The strength of this type of joint is related to several characteristics of the adhesive and the parts to be joined; particularly importance is given to the chemical bonding which is the first step of the joining procedure before the material starts to harden, then to the physical interaction obtained by the secondary forces generated between the atoms and the opposing surfaces finally to the mechanical interlocking that is obtained at the end of the process when the bonding has fully hardened.

To ensure perfect results from the adhesive, some good practices have to be respected, for example the surface of application of the adhesive has to be perfectly clean, especially for the aluminum free of oil; it is also important to not have a smooth surface but to have a roughness in order to ensure good bonding.

Moreover, it is also important to maximize the joint contact area and also, respecting the main characteristic of the adhesive to be strong in shear and tension, the joint has to be designed in order to have the applied stresses aligned to those two types.

The type of adhesive bonding existing on the market are of three types: natural, inorganic, and synthetic. The first two are not so much used in automotive industry because of their low stress capability.

Synthetic adhesive instead, are the most important category and includes thermoplastic[13] and thermosetting[14] polymers and they are characterized by different curing processes, from the catalyst to the increase of temperature up to the radiation or the evaporation curing.

Finally, the pros of using this technology are related to the wide range of material that can be joined, also the flexibility that some adhesives ensure after bonding and to the simplification of the joint design. The cons, instead, are related to the fact that the joint is not as strong as other technologies seen so far and also to the fact that materials have to be firstly prepared and then have to be compatible with the adhesive type.

[13] Thermoplastic is a class of polymers that can be softened with the increasing of temperature and from the soften state can be manipulated.

[14] Thermosetting is a class of polymers that undergoes to an irreversibly hardening.

APPLICATION

All the al-alloys listed in previous paragraph have different characteristics, this makes them suitable for different application in the automotive sector. According to its lightweight and strength it is adopted not only in the design of the structure and the BIW but also in the production of the external aesthetical panels. From a mechanical point of view, they are used for producing engine component like the connecting rod as well as the piston; but also, other components like disk brakes and sometimes also toothed wheels and even for condenser and radiator. In Figure 44 [14] there is a resume of all the possible application of the Al-alloys in the automotive sector together with the series of alloys used in that specific component.

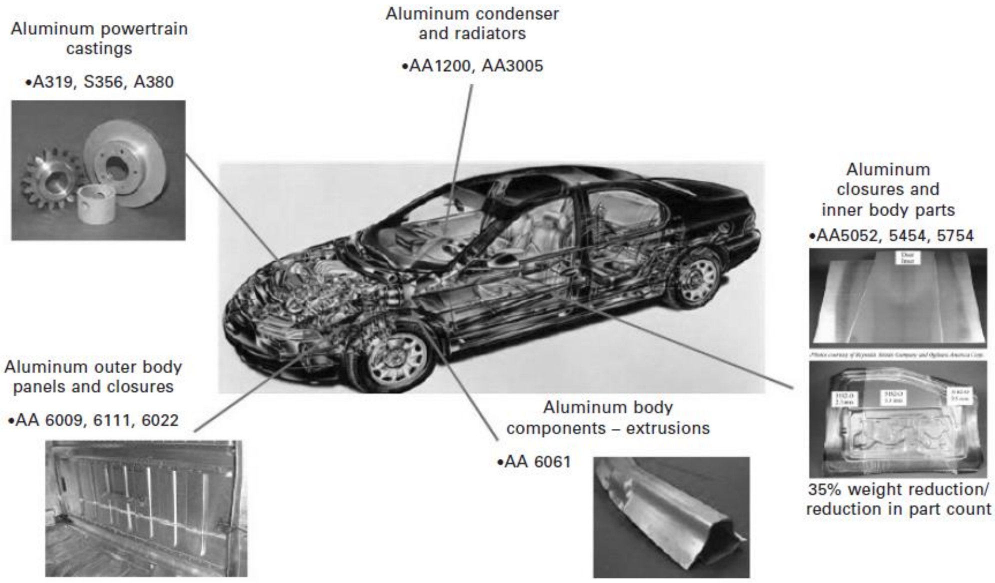

Figure 44: Al-alloys in the automotive sector

CARBON FIBER PROTOTYPE VEHICLE

In this chapter, I will go more in detail of the carbon fiber adopted in the automotive sector for the production of structural and aesthetical parts. In particular I will explain what it is, and what is the aim of use a fiber-based material; then I will talk about the most widespread used processes for the production of carbon fiber products and the application of this technology in the automotive sector.

MATERIAL PROPERTIES

When we talk about carbon fiber, we talk about a composite material which is a material composed of two or more phases which are combined together in order to create a new material with increased properties that are superior respect the two starting materials.

For example, the composites are designed to be strong and stiff and although very light in weight and this give a high strength-to-weight and stiffness-to-weight ratios; this gives better fatigue properties and also has better performance in terms of corrosion respect to steels.

In the fiber composite materials, fibers are used as principal means of load carrier while the polymer matrix is needed not only for keeping the fiber in the right position but also to provide a mechanism that allows the load transfer among the fibers.

In particular, fibers in the matrix can be used in continuous or discontinuous length even if the first are the most used because they are the most effective in carrying the load.

For what is concerned the determination of the mechanical properties it is important to consider the directions to which the fibers are aligned; at these purposes, the rule of mixtures which helps in estimating the modulus of elasticity of the composite material (E_c). To calculate it, we assume unidirectional continuous fiber composite material, which has all the fibers oriented in the same direction and we assume also that the fibers material is much stiffer than the matrix; for this reason, the elastic modulus calculate in the longitudinal direction is equal to the elastic modulus of the fiber (E_f) times the fiber volume fraction in the composite(v_f). In Figure 45 [13] we have a representation of the model considered with the indication where we are estimating the elastic modulus and also a stress-strain characteristic for the fiber and the matrix alone and for the composite material; as can be noticed, the fiber is stiff but has a brittle breakage while the matrix alone is ductile. The composite instead, can be noticed, it is an average of the two components but maintain the same brittle characteristics of the fiber.

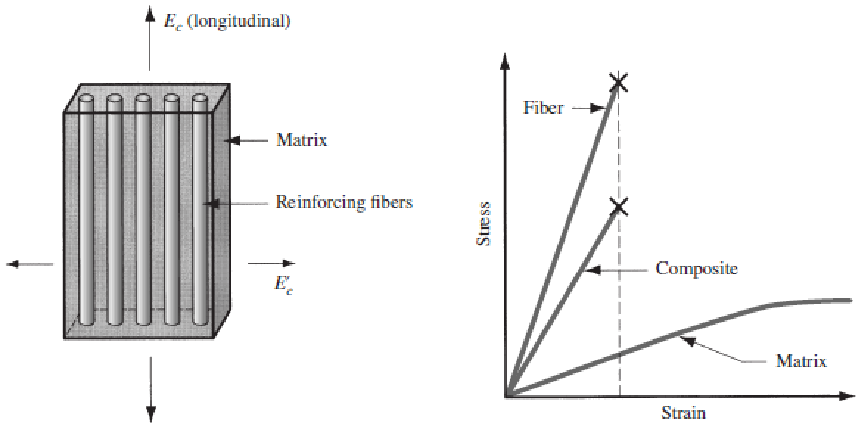

Figure 45: Composite Elastic Modulus estimation model

Despite this, we have to say that the properties of unidirectional continuous fiber composite depend on the orientation of the fibers and from this we can conclude that the highest elastic modulus and strength characteristic can be obtained if the fibers are aligned together with the loading direction. This classify the composite materials as orthotropic materials that opposes to the isotropic materials like aluminum in which, instead, the properties are equal along all the direction of the material.

In carbon fibre composite material, the orientation of the fibres can be varied in order to achieve a desired stiffness or the desired capacity to carry the load. For example, for designing elements which exhibits just uniaxial stress condition, like slender beams or tie rod, the fibres are aligned to coincide with stress direction; for other applications where biaxial stress condition are induced to the piece instead, we can adopt the laminate solution. It consists in using several layers, each one containing unidirectional fibres, but we can join these layers in such a way that more stress direction is covered by simply rotating the layers. In Figure 46 [14] is represented two classical example of a laminate carbon fibre composite materials; in the left one we can appreciate a laminate structure that is able to generate equal modulus in all directions, this consist of rotating each layer containing unidirectional fibre of the following angles: 0°/90°/45°/-45°/-45°/45°/90°/0°; in particular the order is well studied to ensure maximum bending stiffness. In the right representation the layers are rotated of following angles: 45°/-45°/-45°/45° and is a recommended solution for a rod subjected mainly to torsion stress.

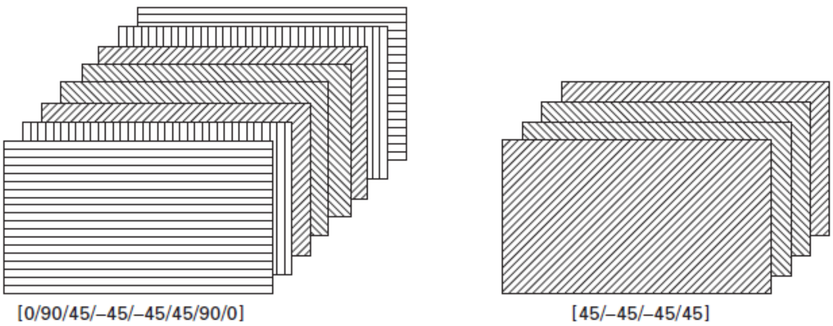

Figure 46:Carbon Fiber Composite Laminates

CARBON FIBRES

Fibres have a circular cross section with a diameter that ranges between 0.0025 and 0.13mm; they are considered as the majors' element that withstand load in a composite material and according to the dimension of the diameter, we are able to improve the tensile strength. As reported in Figure 47 [13], as the diameter decreases, the tensile strength increases, and this is also since the structure become more oriented in the direction of the stress, and thus makes the whole composite material to reduce the possibility of having defects in its structure.

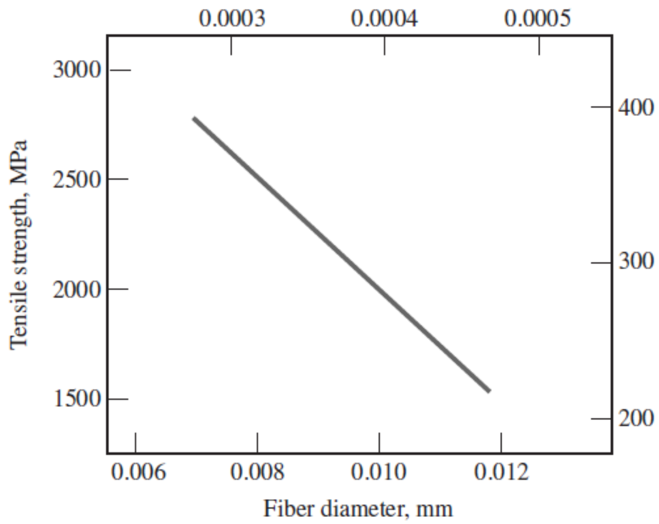

Figure 47: Fiber Tensile Strength vs Diameter

The intrinsic mechanical characteristic of the carbon fibre and, therefore, the characteristic that those give to the composite is strongly influenced by the volume fraction, the geometric characteristics, the density and the type of fibre.

In fact, we can start the production process of the carbon fibre from the polyacrylonitrile, obtaining the so-called pan-based carbon fibre, and from a waste stream of unknown and variable composition obtaining the so-called pitch-based carbon fibre. This is just a type of categorization that I want to take into consideration in this thesis since there are different way of doing so, for example considering their tensile moduli.

PAN-BASED CARBON FIBRES [15]

Pan-based carbon fibres production process consist of three main steps; the first one is a polymerization which is needed to produce the polyacrylonitrile (pan) polymer from an acrylonitrile monomer. The pan is a long chain polymer which has a carbon structure with carbonitrile groups attached to every carbon atom present; this polymer does not melt under elevated temperature, so the second step is a wet spinning process in order to produce fibre precursor.

During this second process, a solution of almost 95wt%[15] of acrylonitrile is formed in order to obtain a concentrated polymer; this solution, originally in a storage tank, is filtered to prevent any impurities and then passes through a spinneret directly into a coagulation bath which contains ethylene glycol that extract the solvent from the fibre. After the coagulation bath, the fibres undergo to a series of post-spinning steps which also includes washing, drawing and drying during which fibres reach their final form. In Figure 48 [15] there is a representation of the complete process described so far.

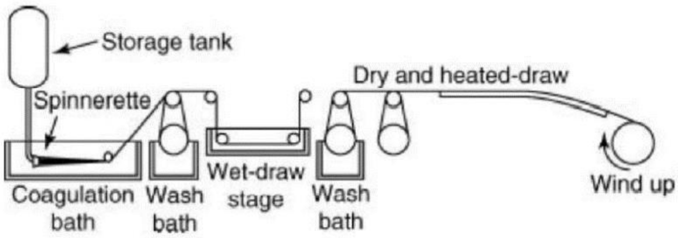

Figure 48: Pan-based Carbon Fibres Wet Spinning Process

The last step for producing pan-based carbon fibre is the carbonization process which is composed of two steps: the first one is an oxidation, which means the fibre undergoes to a heat treatment between 200 °C and 300 °C in an oxidative environment; then they undergo to a carbonization step which consist to a heat treatment process at higher temperature, around 1000 °C, in an inert environment like nitrogen.

According to the mechanical characteristics of the pan-based carbon fibre we have the following classification based the value of the elastic modulus; in particular, the three categories are:

- High Strength Carbon Fibre (HS) characterized by a modulus lower than 250 GPa.
- High Modulus Carbon Fibre (HM) characterized by a modulus lower than 440 GPa.
- Ultra-High Modulus Carbon Fibre (UHM) characterized by a modulus greater than 440 GPa.

According to the characteristic seen so far and reported more in detail in Table 8, the type of carbon fibre chosen to develop our component is the pan-based high strength Carbon Fibre.

	HS carbon fibre	**HM carbon fibre**	**UHM carbon fibre**
Density [kg/m^3]	1800	1850	2100
Elastic Modulus [GPa]	230	400	700
Tensile Strength [Mpa]	5000	3000	1500
Maximum Deformation [%]	2	0.9	0.3

Table 8: Pan-based Carbon Fiber Mechanical Characteristics

[15] wt% is the percentage in weight of a solute into a solvent.

PITCH-BASED CARBON FIBRES [15]

As should be clear now is that the purest is the material that is polymerised and the least defects will have the final fibre produced, with pitch-based carbon fibre the concept is totally the opposite; in fact, now the starting material come from waste which has unknown and variable composition. The pitch that results is full of hydrocarbons that is the residue of the oil refining process or the cooking process; this pitch is composed of 80% to 90% of carbon and this make it interesting for using as precursor for carbon fibres.

Pitch is a glassy solid at room temperature but get soft as the temperature increases in the range between 40 °C and 200 °C, and at 280 °C has sufficiently low viscosity to be drawn for creating fibres. From there we can create two types of fibres: low strength coming from isotropic pitch and high strength coming from mesophase pitch.

Isotropic pitch-based carbon fibre has the lowest value of strength and modulus, but they are the least expensive to be produced and they are obtained from a low-aromatic pitch by a stabilization process followed by a carbonization one.

Once the pitch has been melted, there are two ways for producing fibres from it: the first is the centrifugal spinning in which the pitch is dropped on to a pinning plate with holes on the circumferences and pitch is pushed through these holes thanks to the centrifugal forces; the second process is the melt blowing in which a molten flux of pitch is extruded into a high-speed stream of gas which attenuated the fibres.

In mesophase pitch-based carbon fibres, the pitch is instead treated in order to give to the molecular structure a liquid crystalline structure. In fact, during the thermal treatment of the aromatic hydrocarbons in a temperature range that goes between 400 °C and 500 °C an intermediate mesophase (liquid crystalline structure) of spheres is created and each one of those spheres has a single direction of orientation. As the process continue, the spheres continue to grow until a phase inversion is reached and mesophase is transformed into a continuous phase. Then the precursor of the fibre is produced by simply spun from the melt.

The formation of the mesophase can be influenced by several factors like the presence of insoluble particles as well as the presence of oxygen or sulphur; the main processes for obtaining the mesophase are the heat soaking which consist of converting a 50wt% of low cost isotropic phase into mesophase thanks to a heat treatment of 40 hours at 400 °C; during this process, the mesophase collapse at the bottom of the vase due to its higher density, than after a mixing during the pyrolysis[16] we obtain an homogeneous

[16] Pyrolysis is a thermo-chemical decomposition process obtained thanks to the application of heat in an inert environment.

emulsion between meso and isotropic phase that helps in obtaining a more spinnable product.

The second method for producing mesophase is thank to the extraction technique thanks to an organic solvent like benzene; the remain insoluble fraction undergoes to a pyrolysis for 10 minutes at a temperature range from 230 °C to 400 °C giving rise to a mesophase product at 75 to 100 wt%.

the following step is to produce the fibres by using the melt spinning method that is reported in Figure 49 [15] and consist in an extruder which melts pitch particles and pump them through a spinneret. The high extension shear stress that the molten pitch undergoes, helps in orienting the liquid crystalline mesophase.

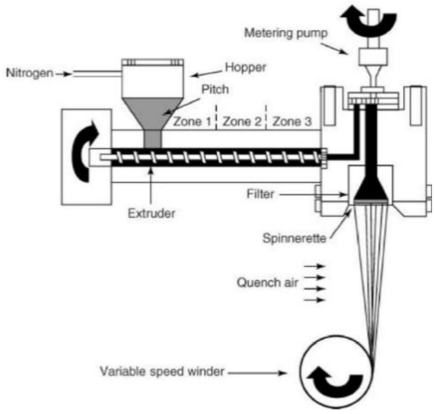

Figure 49: Mesophase Pitch-based Carbon Fibres Melt Spinning Process

The already spin fibres, now undergoes to a process of stabilization in which the oxygen reacts with the side groups of the fibres resulting in a 6% of weight gaining; and then they undergo to a carbonization process which is operated in two steps: the first at 1000 °C and the final one at 3000 °C.

CARBON FIBRES PROPERTIES [15]

The main characteristics that make the carbon fibres so interesting, over conventional materials, are the high tensile strength and modulus; those characteristics are mainly influenced by the defects that can be present, as a matter of facts, the biggest is the defect and the more are the failure that occurs at low stress.

Another interesting property of the carbon fibres is their elasticity which is caused by the covalent bond which are created within carbon atoms; this elasticity ensures, contrary to any metal behaviour, that fatigue damages doesn't occurs by loading and unloading cycles, but large loading cycles can induce damages and failure.

An important feature that makes both pan and mesophase pitch-based carbon fibre on a higher-level respect all the other material is that they are not subjected to creep or fatigue failure; in fact, these types of carbon fibre can withstand two million cycles at a stress level that ranges between 296 and 861 MPa while common steel fails after three million of cycles at a stress which is one tenth to one quarter lower. Moreover, a test for creep investigation has been conducted at 2300 °C under a stress of 800MPa and its result was negative.

Another important feature of the carbon fibres is their low thermal expansion coefficient which has been estimated as one order of magnitude lower than conventional metals.

Going more in detail of the pan and pitch-based carbon fibres mechanical characteristics, in Figure 50 [15] we can appreciate a strength versus modulus characteristics for the pan-based as well as for the isotropic and mesophase pitch-based carbon fibres. As can be seen, the three configurations act on three different strength/modulus zones; but has to be reported that the mesophase pitch-based could potentially covers the whole spectrum covered by the pan-based but this potential remains unexpressed since the manufacturing process is easier if a completely a fully synthetic material is used to obtain the fibres instead of using a semi-natural raw material.

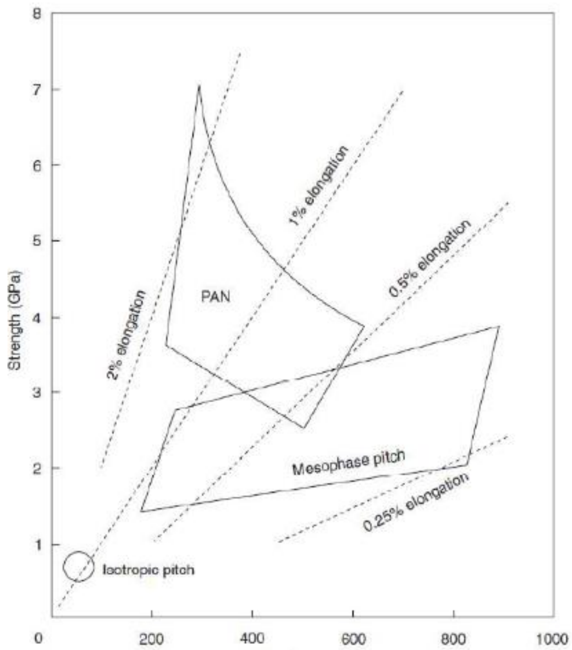

Figure 50: Carbon Fibres Strength vs Modulus Characteristic

Considering the thermal and electrical conductivity of the pan and pitch-based, we can say that mesophase pitch-based carbon fibres has the highest electric conductivity and lowest resistivity and so we can consider the inserting of fibres as a clever way to increase the electric conductivity of a nonconductive material. Following the same trend, the mesophase pitch has also the highest thermal conductivity. Those characteristics are reported in the two graphs of Figure 51 [15].

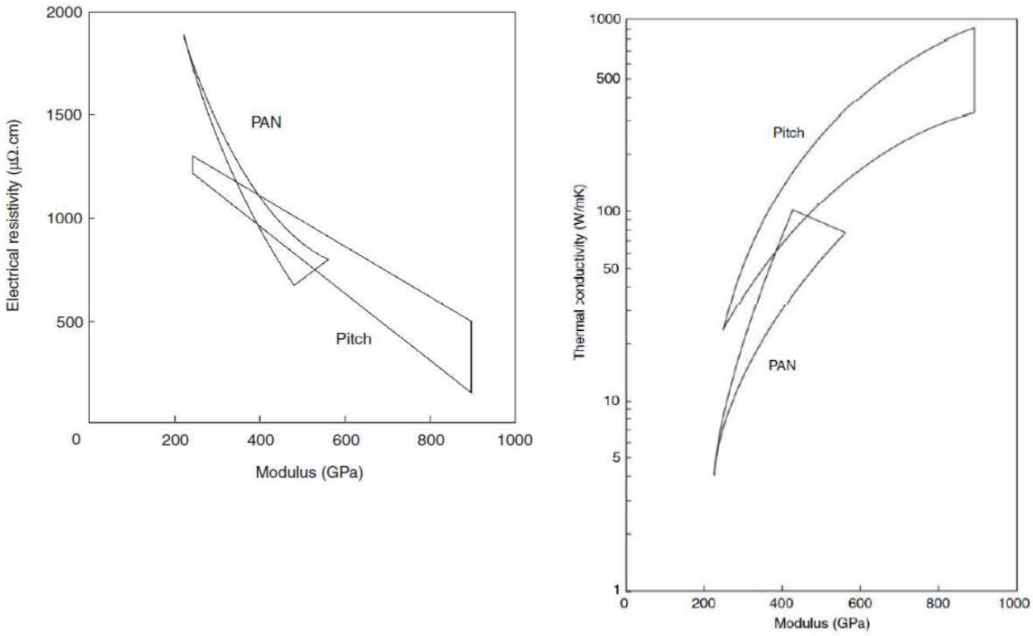

Figure 51: Carbon Fibres Electric and Thermal Characteristic

MATRIX

The matrix in a composite material brings lots of advantages both to the material itself and to the fibres, for example it keeps those in please, it is used to distribute load among fibres, but also to protect the composite material from the external agent. The correct choice of the matrix material is extremely important since it influences the mechanical characteristics of the whole composite material concerning the compressive or interlaminar shear or the lateral support for preventing the occurrence of buckling and so influencing the compressive stress.

Among all the materials, our interest is devoted to the polymer that can be split into thermoset polymers, like epoxies, which are more commonly used in continuous or long-fibre composites; and thermoplastic polymer which instead are more common for short-fibre composites.

POLYMER MATRIX [16]

A polymer is a molecule characterized by a long chain which contains one or more repeated unit of atoms which are joined thanks to covalent bond. A polymeric material, therefore, is a collection of more molecules of polymers that are fixed in space.

As already said, the polymers can be divided into thermoplastics and thermosets; the first one is characterized by molecules that are not bonded together with primary bonds but with secondary bond, so their link is quite weak. With the increase of the temperature the bonds are temporary broken and then when the temperature goes

down, they are restored; what occurs to the material is that it undergoes to softening then melting and finally it is reshaped.
The thermoset polymers, instead, are chemically linked by cross-links that forms a rigid, three-dimensional structure. Once those links are formed, they cannot be melted; sometimes, if the number of links is low enough the material can be softened.

Creep and relaxation tests are performed on the polymeric material in order to better understand which are the viscoelastic characteristics; the creep test is performed by supporting a constant stress on the specimen while it undergoes to a monitored deformation, as the material start to creep the strain increases. The relaxation test, instead, is made applying a constant deformation while monitoring the evolution of the stress over the time. In thermosets, both creep and relaxation behaviour show a descendant trend.

In order to understand which of both has to be chosen for having a matrix which shows good properties, some mostly desirable feature has to be respected; those are: a high tensile modulus which acts on the compressive strength of the final composite material, a high tensile strength which controls possible crack inside a laminate structure and finally a high fracture toughness which prevents delamination.
Anyhow there are also some considerations that has to be made on the dimensional stability over the increase of temperature and also on the resistance to moisture and solvents. This is possible if the material has a glass transition temperature that goes over the maximum utilization temperature.

According to all the evaluations about the characteristics of the two types of polymers, the thermosets are widespread used as matrixes for fibre-reinforced composite materials. Advantages are related to their thermal stability and chemical resistance apart from the already explained ones; while the disadvantages are related to the limited storage life, the long period of mold fabrication and the low strain-to-failure capacity.

THERMOSET MATRIX – EPOXY [16]

This type of material is the most used as a matrix in carbon fibre reinforced composite material and it starts as a low-molecular-weight organic liquid resins which contains epoxide groups.
This organic liquid undergoes to a polymerization reaction which transform it into solid state thanks to the addition of reactive agent before to insert the fibres into the liquid; the resulting material is a solid epoxy polymer.

The polymerization time and the temperature at which it occurs depend on the type and the amount of the inserted agent, sometimes it is possible to have an acceleration of the process by mix to the liquid some substances.

The usage of the epoxy material as a matrix brings to the composite the following advantages: huge range of properties since many starting materials, absence of volatile material, low shrinkage during polymerization, good resistance to chemical substances and good adhesion to a wide variety of fibres. Disadvantages, instead, are related to cost and polymerization time.

In Table 9, there is a recap of the main mechanical properties of the thermoset epoxy matrix.

	EPOXY RESIN
Density [kg/m^3]	1200
Elastic Modulus [Gpa]	4.5
Tensile Strength [Mpa]	96
Elongation [%]	2 (at 100 °C)
	6 (at 200 °C)
Heat Capacity [J/kg°C]	1000
Thermal Expansion Coefficient [°C^{-1}]	11e-5

Table 9: Epoxy Resin mechanical characteristics

PRODUCTION PROCESS

The production processes consist into the curing of the thermoset resins using elevated temperature and high pressure to provide enough force to the resin to flow into the fibers in the mold. The time needed for the perfect curing to occur is extremely important and is desirable to optimize the process in order to be able to have the shortest time.

One of the earliest techniques was the hand lay-up technique that has now been replaced with other techniques, particularly in the automotive industry, such as the compression molding and the resin transfer molding that will be, both, treated below. [14]

COMPRESSION MOLDING

It is the most widespread used manufacturing techniques for producing thermoset-matrix fiber reinforce composite materials in the automotive sector for its high rate of production and its ability to easily manage large pieces with complex shapes.

One of the main requirements for processing this type of technique are the metal dies that are used both for the production of structural and exterior panels.

The advantage of using this technique is that the cost of the tools is lower respect to the cost for stamping the same part in aluminum and for this, compression molding is highly considered when the production volume per year is in the range between 150000 and 200000 pieces.

This production process uses the so-called sheet molding compound which consist of thin layers containing fibers which are dispersed in a highly viscous thermoset resin and the curing od this resin takes place during the compressive phase.
In particular, what occurs is that applying the heat during the compressive phase, the viscosity of the resin is reduced in order to permit it a better flowability in the mold. For this reason, the process takes place under a temperature of 150 °C and a pressure that ranges between 2 and 25 MPa; while the period of closure of the mold varies between 1 and 3 minutes according to the thickness of the part to be produced.

RESIN TRANSFER MOLDING

This process consists of resin that is injected into the molding thanks to the high pressure and diffuses through a series of dry layers of carbon fibers. These resins can be inserted either by a single port or by more ports and the injection pressure varies between 0.4 and 1 MPa, this helps in eliminating all the air trapped between fibers.
After the curing phase has finished, post treatment procedure may be necessary for trimming all the part outside of the edges for achieving the correct final piece.

This production process has low tooling cost and the mold clamping elements are simple; moreover, the process involves a low pressure respect the precedent process and also give the possibility of incorporating metal inserts for increase the stiffness of a portion of the final component.

This type of process is extremely considered if the production volume per year is in the range of 5000 to 50000 of pieces.

FINAL CONSIDERATIONS

Carbon fiber reinforced thermoset-matrix composite has attracted lots of interest for what the weight saving potential is considered; despite this, they have found low application especially on high volume production vehicles for the increase of cost that we would have. Their field of applicability concern more sport car and low volume production vehicles.
In those type of vehicles, they are not only used for aesthetical panels or for finishing component, but they are used also for structural part; in fact, is used in sports cars the

usage of a structural monocoque, as can be seen in Figure 52. This is able of ensuring a weight saving and also the safety standards for the driver or any other occupant.

For what concern the mechanical properties of the CRFP, it is important to know perfectly all the characteristics of both the material. In particular, it is important to know the thickness of the fibers layer and the percentage in mass and in volume of the fiber over the whole composite material and this is strongly dependent on the mechanical behavior that the component has to accomplish to and on the production process.

For what is concerned the CRFP skeleton, the production is made through the compression molding and for this process we have a percentage in volume of the fiber over the total volume of the composite that varies around the 50%.

According to the mechanical properties explained in Table 8 and Table 9 of the material chosen in the production process, in Table 10 there are the mechanical properties of the composite material epoxy plus fiber. The percentage and the values of the mechanical properties are not the precise one used by the company because they can vary according to several factors.

	Epoxy resin + HS carbon fiber
Density [kg/cm^3]	1500
Elastic Modulus [GPa]	145
Tensile strength [MPa]	1200
Compressive Strength [Mpa]	1450

Table 10:Epoxy resin + HS carbon fiber mechanical properties

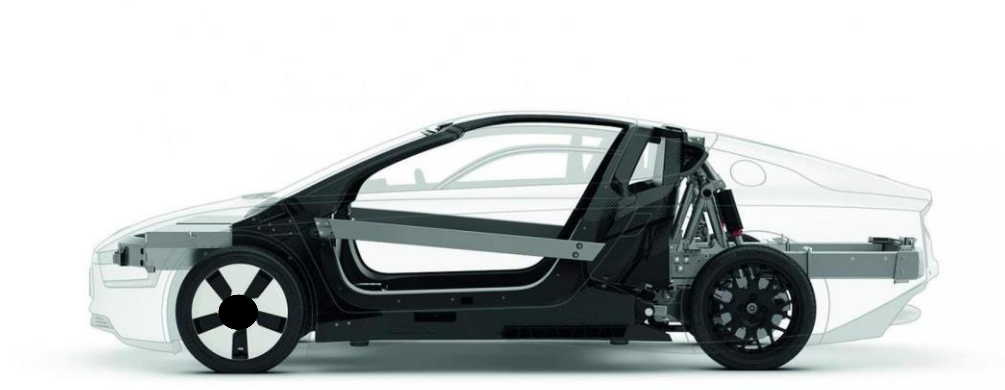

Figure 52: Carbon Monocoque Structure

COMPONENT CASE STUDY DESIGN: ALUMINUM vs CARBON

The following chapter is the heart of the whole thesis and contain the result of my work in Magna Steyr Italia. During my internship I project the hood of a luxury car both for a production in aluminum and carbon with the aim to highlights which are the difference in the design stages approaching to two dissimilar materials that have distinctive characteristics in terms of strength, deformability and processability.

The aim of this chapter is to show all the mandatory steps that has to be followed during the design of a hood skeleton, which are the constrain which influence the design, which are the rule imposed for the occupants and pedestrian safety, the method of production and the limits of the material during its processability.

CAD DESCRIPTION

The software used to develop my project is the CAD/CAE/CAM[17] software CATIA V5. It has been developed between the ‘70s and ‘80s and is widespread used across lot of engineering company because it is able to support lots of phases of the product life, from the design to the production and the analysis.

In particular CATIA V5 relies on a kernel including a parametric modeler of surfaces and solids, this uses NURBS[18] curves as internal representation of surfaces.

DESIGN CONSTRAINTS

A fundamental aspect in the design of a generic component is to analyze all the constraints, so in this chapter I would like to express all the pathway that I have made before starting the design process on the software.

In particular, for the design of a hood skeleton I had to consider all the interfaces that the component has with the vehicle, all the characteristic of the material used for the production and even all the regulations that imposes a certain characteristic.

As already said, my project was to develop a hood skeleton of a luxury vehicle; to make this I was provided with the “hood skin” that is the external aesthetical part of the vehicle that is the one provided by the style department and taking this as first constrain the modelling of all the skeleton take place. Next to this, I was also provided with all the

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[17] CAD: Computer-aided Design; CAE: Computer-aided Engineering; CAM: Computer-aided Manufacturing

[18] NURBS: Non-Uniform Rational Basis-Splines; set of geometric curves used for representing curves and surfaces.

constrains not given by the aesthetical surfaces but from the closures or by the hinges or other mechanical interfaces.

VEHICLE INTERFACE

This is the first stage that I faced, it started with Magna Steyr Italia that provides me the “hood skin” and all the objects that has to be mounted on or that do not depend on the design of my piece but are taken as constraints for my work.

In Figure 53, I have highlighted in assorted colors all the surfaces that I must take as reference for the modelling of my hood skeleton; those, are directly in contact with the vehicle or thanks to a subcomponent, like seals or glue.

Starting from the top of the picture, in purple there is the surface of the hinge where the hood is attached to the vehicle and thanks to it, is able to opens; the objective in that zone was to create a part of the skeleton on which the hinge is able to perfectly interface with that final surface.

The second constrain was the yellow surface. The car from which is taken the hood is an electric car and therefore it does not have front engine; in its substitution there is a trunk and therefore the yellow surface is the seat where the external seal of the trunk goes in contact. In this region is important to guarantee the correct space and to keep the given shape for the seal.

The third interface with the vehicle is the green surface that is the seat of the closure of the hood and is a direct interface of the skeleton with the vehicle structure. It is particularly important to keep the same surface for the entire length in order to guarantee a perfect fit and a perfect closure between the hood and the vehicle.

The two circumferences, the orange and the blue ones are two seats where the bumper, which are mounted on the car structure, interfaces with the skeleton itself.

In Figure 54, we can see the constraint surfaces from the lateral view in order to understand their mutual position respect the z axis.

It is important to point out that those surfaces that we are taking as constrain are not the only zone where the skeleton touches any other component since to those, the gluing sites to the hood skin has to be added; although, they are those that has to maintain their position since a change in it will imply a bad fit with any other component that can cause an imperfect fit or even damages.

Figure 53:Hood skeleton interfaces with the vehicle top view

Figure 54: Hood skeleton interfaces with the vehicle lateral view

PEDESTRIAN SAFETY

When project of a hood take place, considering the pedestrian safety is of primary importance in order to protect people in a car-man impact in order to reduce as much as possible the injury caused.

For this reason, Euro NCAP have foreseen a pedestrian testing protocol in order to assess for pedestrian safety; the more the care is compliant with this protocol and the more is the star rating evaluation that is assigned to the manufacturer.

An important phase of the testing procedure of a vehicle is the marking and measurement procedure that should be made with the vehicle in its normal ride attitude; moreover, the head form impactor test zones will be marked on the vehicle with the bonnet in the undeployed state, this is made to avoid the possibility of having discontinuities in the test areas that could bring to anomalies.

In particular, the reference lines are taken both for the bumper and for the bonnet, this because the test performed for pedestrian safety concern both the vehicle's parts.

However, for the purpose of this thesis we will concentrate just with the regulation and the testing procedure that will deal with the front hood.

First of all, the hood leading edge line has to be considered; it is defined as "the geometric trace of the points of contact between a straight edge 1000mm long and the front surface of the bonnet, when it is inclined by 50° respect to the vertical longitudinal plane and with the lower end 600mm above the ground" [17]. Those measures can be slightly changed in particular cases; for example, if the hood is inclined by 50° so that the leading edge of 1000mm length underline a solid contact line instead of a single point, the inclination of the leading edge could be reduced to 40°.

The contact point of the leading edge with the hood has to be marked. In Figure 55 [17], we can understand better the way the leading edge has to be constructed in order to mark the reference line on the hood.

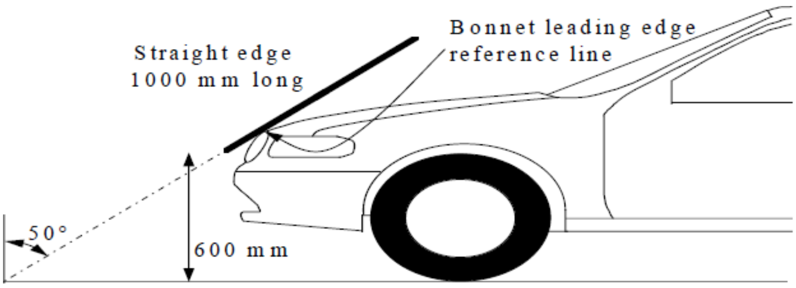

Figure 55: Leading Edge Reference Line

The second reference line that has to be carefully considered is the Bonnet Side Reference line that is defined as "the geometric trace of the highest point of contact between a straight edge 700mm long and the side of the hood and A-pillar, when it is inclined of 45°". In Figure 56, we can have the clearest sketch of the selection of the side reference line. [17]

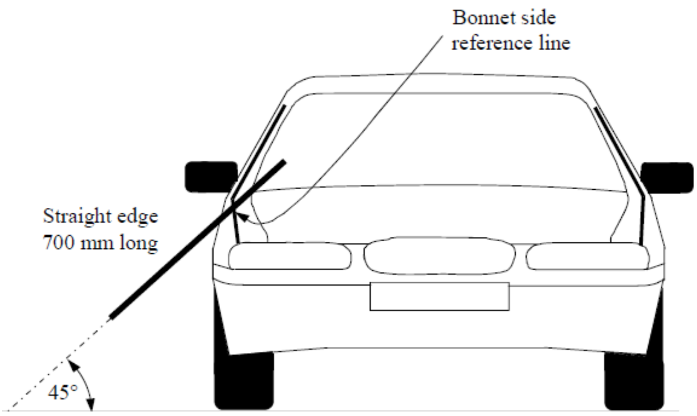

Figure 56: Side Reference Line

Then, as reported in Figure 57, the Corner Reference point is defined as “intersection of the Bonnet Leading Edge Reference Line and the Bonnet Sideline.” [17]

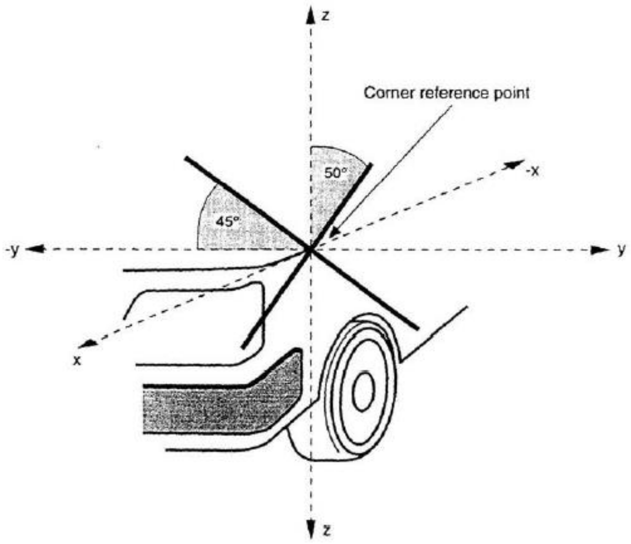

Figure 57: Corner Reference point

An important definition as to given to the Bonnet Top that is stated as “ the outer structure that includes the upper surface of all outer structures except the windscreen, A-pillars and structures further rearwards of them; it is bounded by the geometric trace of the 1000mm wrap around line in the front, side reference line and the base of the windscreen”. [17]

Other marks on the bonnet top are reported, in particular the 1000mm, 1250mm, 1500mm, 1700mm, 1800mm and 2100mm Wrap Around Lines; those are geometric lines traced on the top of the bonnet thanks to a flexible tape and starting measuring from the ground. In Figure 58, [17] we can understand better how the lines are traced and how the measurements start.

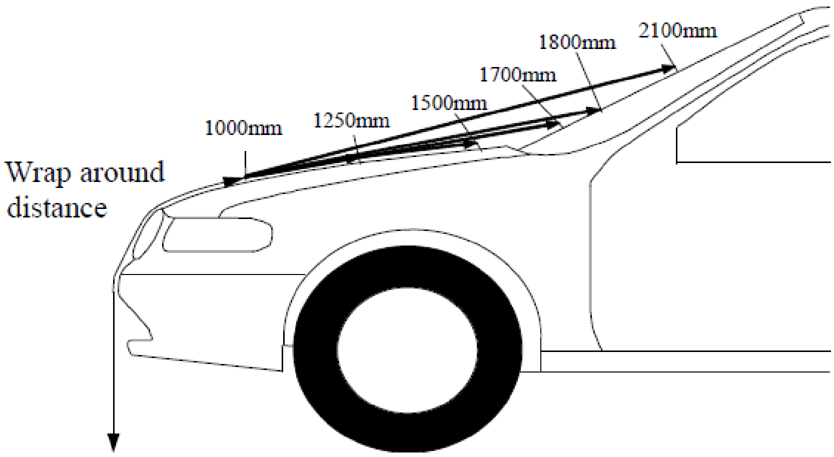

Figure 58: Wrap Around Geometric Lines

Those lines defined in this way are of primary importance in subdividing the bonnet top in zones that are used in testing for pedestrian safety for different aged people. For example, the wrap around lines between the 1000 and 1500 mm identify the child zone while the lines between the 1500 and 2100 mm identify the adult zones. In Figure 59 [17], we can see from the top, all the lines and the two zones identified for child and adults.

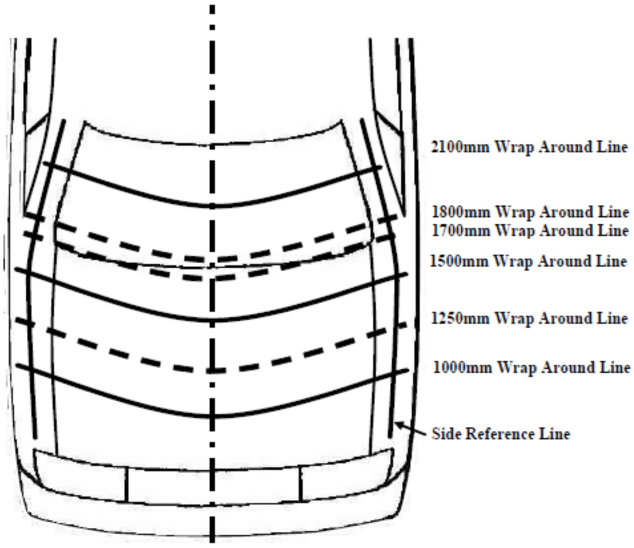

Figure 59: 1000mm to 2100mm wrap around lines top view.

Then starting from the three solid lines of 1000, 1500 and 2100mm, they are divided in twelve equal distance pieces and the marked points are then connected together. In this way, both the child and adult areas are divided in six macro areas, each one divided in four quarters. In Figure 60 [17], we can notice that the child zone is labelled with the letter "C", so the six macro zones are C1,C2,C3,C4,C5,C6; with the same logic, the adult zone is marked with the letter "A" and the six macro zones are identified as A1,A2,A3,A4,A5,A6. Inside each macro zones, the four quarter are labelled A, B, C, D from the top-left one and following a clockwise direction.

Those way of dividing in zones which are smaller than the previous and of labelling each macro and micro zones is a way to perfectly organize the way of working during the test. In fact, according to the virtual test conducted, Euro NCAP decide which zone has to be assessed with the impact procedure and, have all the zones declared, it is easier to understand were to perform the impact.

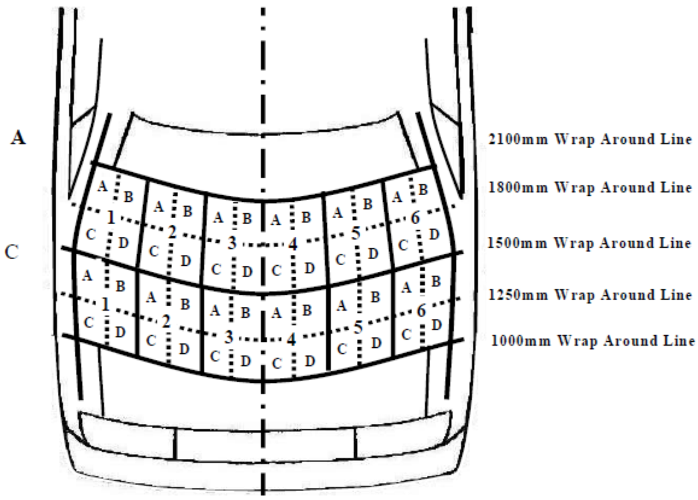

Figure 60: Labelling of the head form test zones

For what the head test is concerned, it is conducted with the bonnet in fully deployed position, and it is intended to remain unchanged before the smallest appropriate stature pedestrian head impact time. In particular, the manufacturer is required to provide to Euro NCAP the results of numerical simulations of the impact test performed with the car travelling at 40 km/h with all pedestrian statures.

From this test, the head contact time, and the wrap around distance to which the head enter into contact with the hood is registered and as reported in Figure 61, a graph comes out where the two parameters are put into relation considering the stature of each manikin.

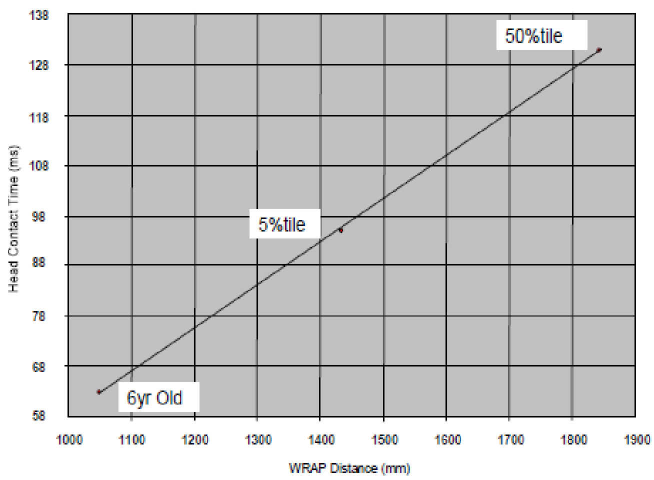

Figure 61: Head Contact Time vs Wrap Distance

In particular, different impact direction are used for distinct size of impactor; in fact, the angle of impact for the test of a child/small adult impactor is 50° with a tolerance of ±2°; while the angle of impact of an adult is 65° ±2°. Moreover, when the impact occurs, the first contact point should be within a ±10mm respect to the chosen impact point; while, for what the speed of impact is concerned, the propulsion system is accelerated up to a velocity of 11.1 ± 0.2 m/s at the contact moment.

All the impactors are equipped with sensors so to be able to record data of the impact; these are than compared with the limits reported in Table 11 in order to understand the severity of the impact.

Body Form Impactor	Injury Criterion	Limit
Child/ Small Adult Head form	Head Injury Criterion	1000
Adult Head Form	Head Injury Criterion	1000

Table 11: Head impact test limit

DESIGN SEQUENCE

Once understood all the constrains that I had to consider before starting my design process, I create the hood skeleton. I have made two separate projects for the aluminum and carbon hood because the two had some distinct aspects to be considered as well as different fastening methods and different reinforcements.

In both cases I have started from the skin of the hood that was a datum and first of all I modified it in according to the joining method to fix skin and skeleton.

In this section I would provide the design sequence for both the projects, I will explain which are the differences and why we had to make those choices and finally I will provide an overview on the fastening methods.

ALUMINIUM HOOD

Starting from the skin, the first action was to make a proper seat for the glue for join the skin and the skeleton. As already seen, for external aluminum panel which has aesthetical purposes, the only feasible way is to use the hemming joining process.

It consists of folding the external panel by 180°, creating a hem where inside is inserted the inner panel and the glue; by pushing the hem, the inner panel is kept in position and then the glue provides a structural joining.

As can be seen in Figure 62, I had to create the hem to the skin keeping a gap of 1.75mm in order to have enough space for the skeleton of 1.5mm of thickness and a layer of glue of 0.25mm thick.

Its worth of note that the skin has been provided to mee as a surface, for this reason, after the creation of the hem, I had to create a solid from it and so, I gave to the surface a thickness of 1mm as can be seen in Figure 63.

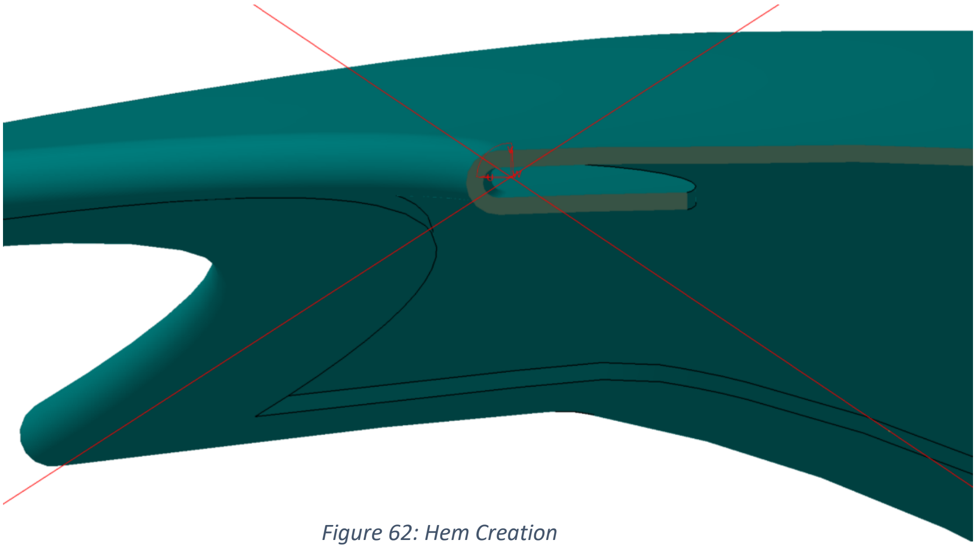

Figure 62: Hem Creation

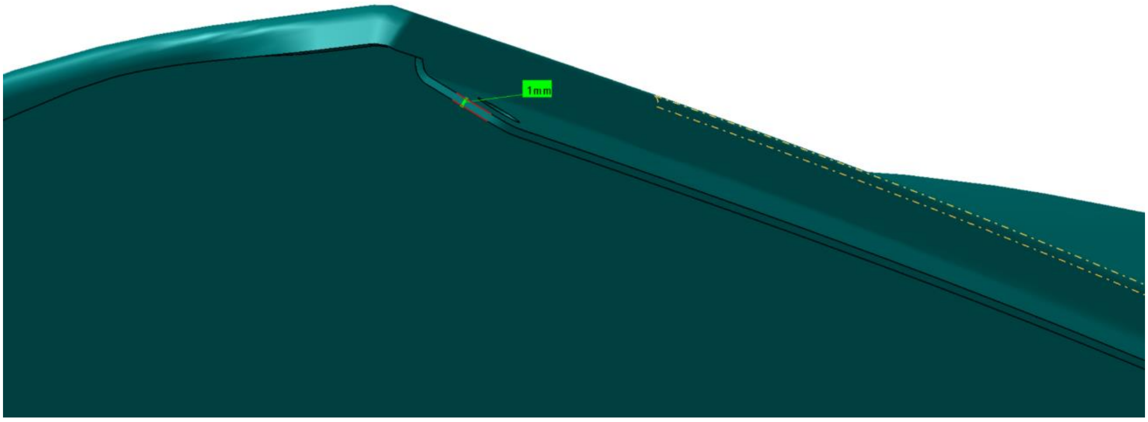

Figure 63: Skin Thickness

As can be seen in Figure 64 and better in Figure 65 the upper part of the skin, the one near to the windscreen, does not have a hem but a simple flange. In fact, in that region, the skeleton in joined using spot welding; this choice come from the knowledge that the part is not exposed to the customer sight cause have to be covered with a gasket.

In particular, in Figure 65 we can see a transition region to connect the ham with the flange.

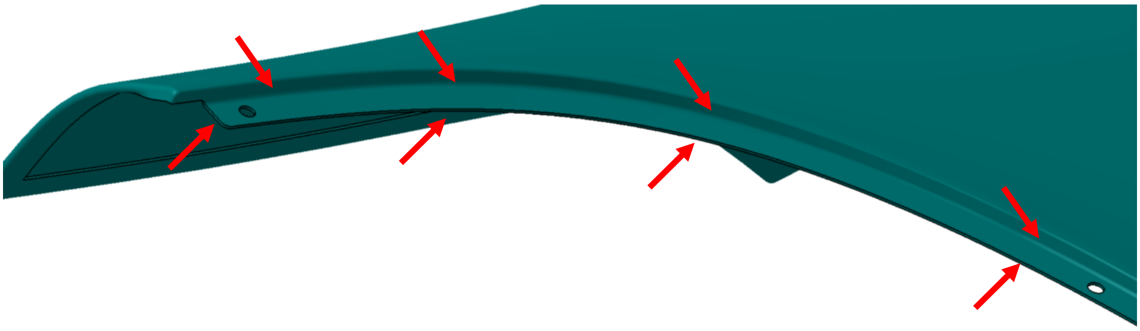

Figure 64: Flange region

Figure 65: Transition region

Once finished the skin, I design the skeleton starting from the surface inside the hem where it goes in contact and by create an offset of the internal part of the skin. What comes out, as can be seen in Figure 66, is a solid skeleton with a flange running all around that allow the connection with the skin.

Figure 66: Aluminum Skeleton step 1

The process to create the final shape, continue considering the constrains and the surfaces that should be respected, as reported before.

So firstly, I create the central trace containing both the trunk seal seat and the interface surface with the hood closure, Figure 67; then the seat for the hinges, Figure 68; the seat for the external bumper, Figure 69.

Moreover, I create the seat for the lateral gluing and the central gluing sites with the skin (anti-flutter glue[19]), Figure 70 and Figure 71. It worth of note that those type of gluing are different from the one used in the hamming process; in fact, the gap is higher in order to contain a glue layer of 3mm of thickness.

Finally, also the last seat for the internal bumper is added, Figure 72.

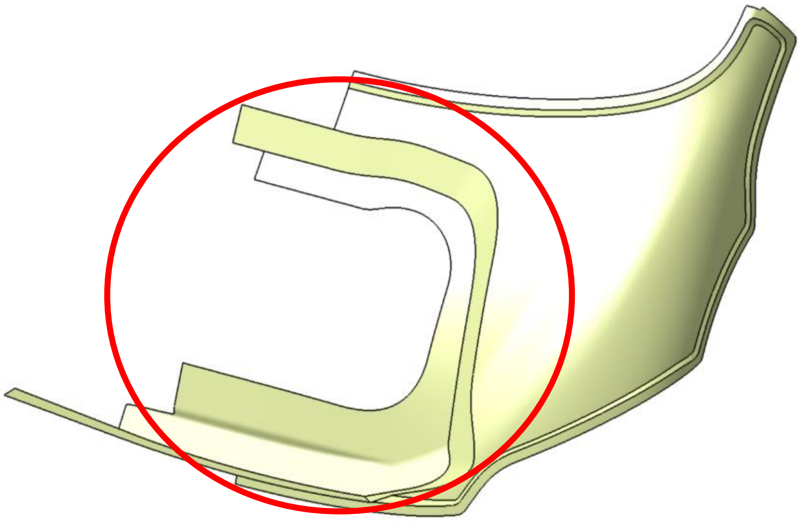

Figure 67: Aluminum Skeleton step 2

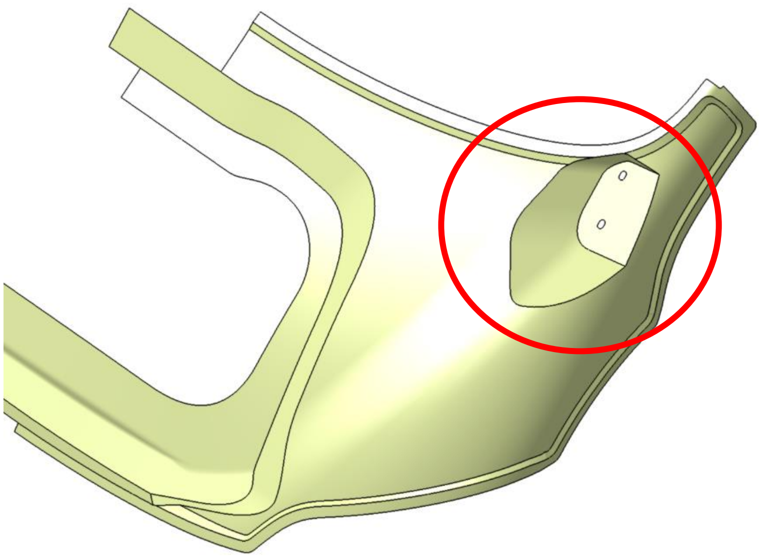

Figure 68: Aluminum Skeleton step 3

[19] Anti-flutter glue: type of adhesive between two panels for controlling vibration.

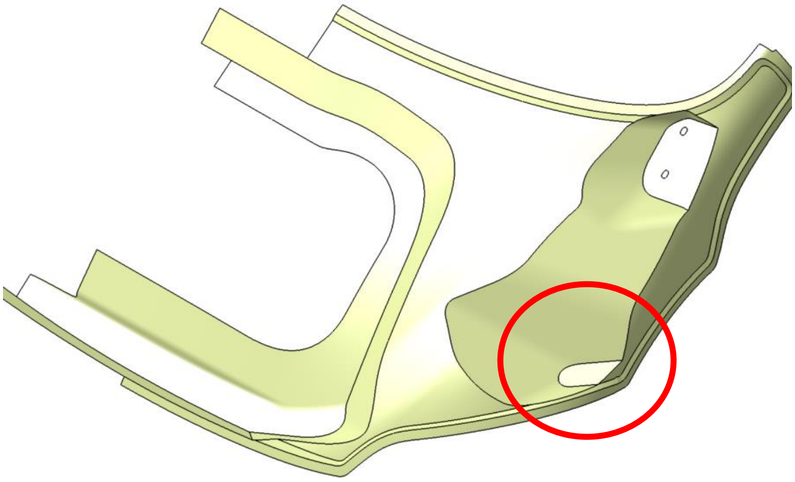

Figure 69: Aluminum Skeleton step 3

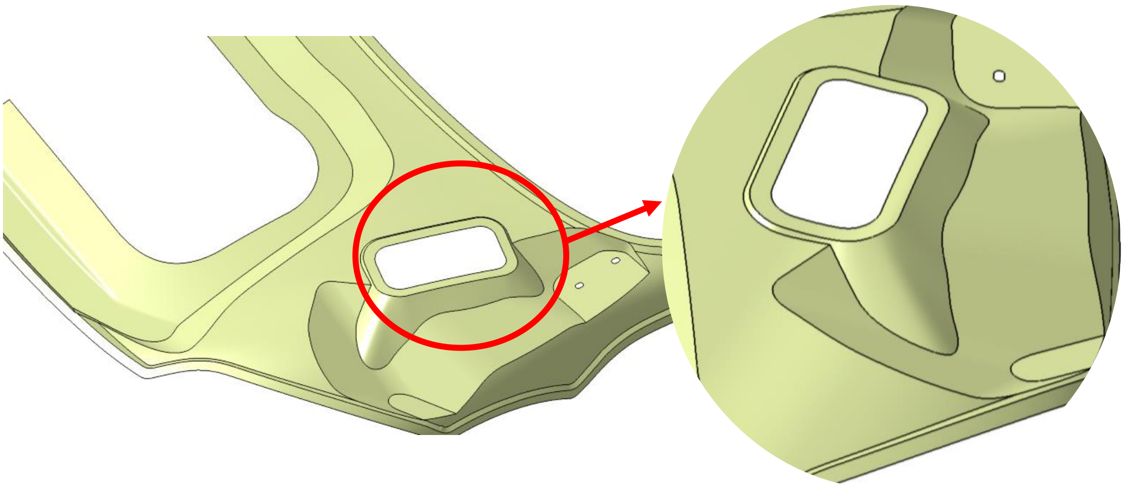

Figure 70: Aluminum Skeleton step 4

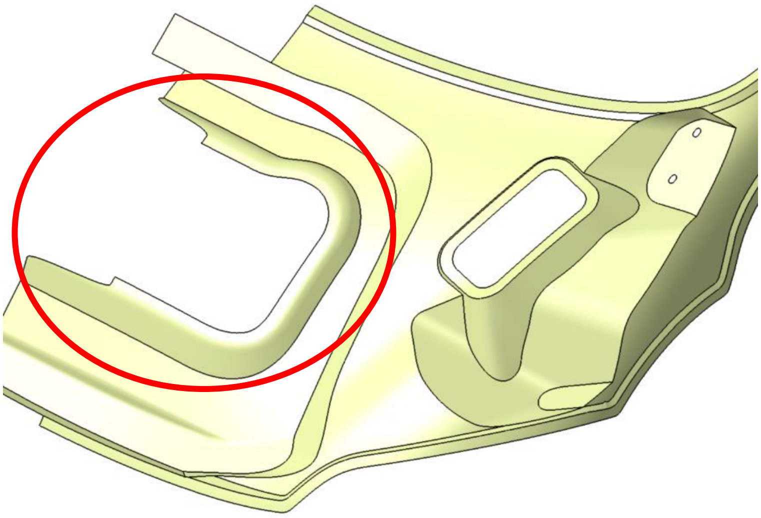

Figure 71: Aluminum Skeleton step 5

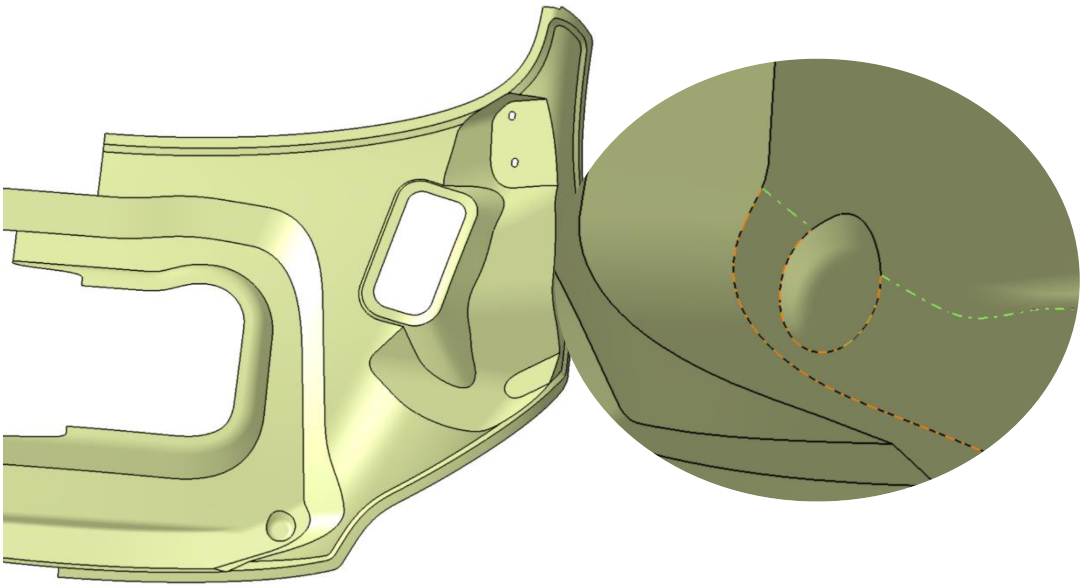

Figure 72: Aluminum Skeleton step 6

Before completing the skeleton, I had to add a little surface in the front part of the center gluing site; this was important in order to create a seat for the closure reinforcement. As can be seen in Figure 73, a little step has been added just in the front part, where the closure is.

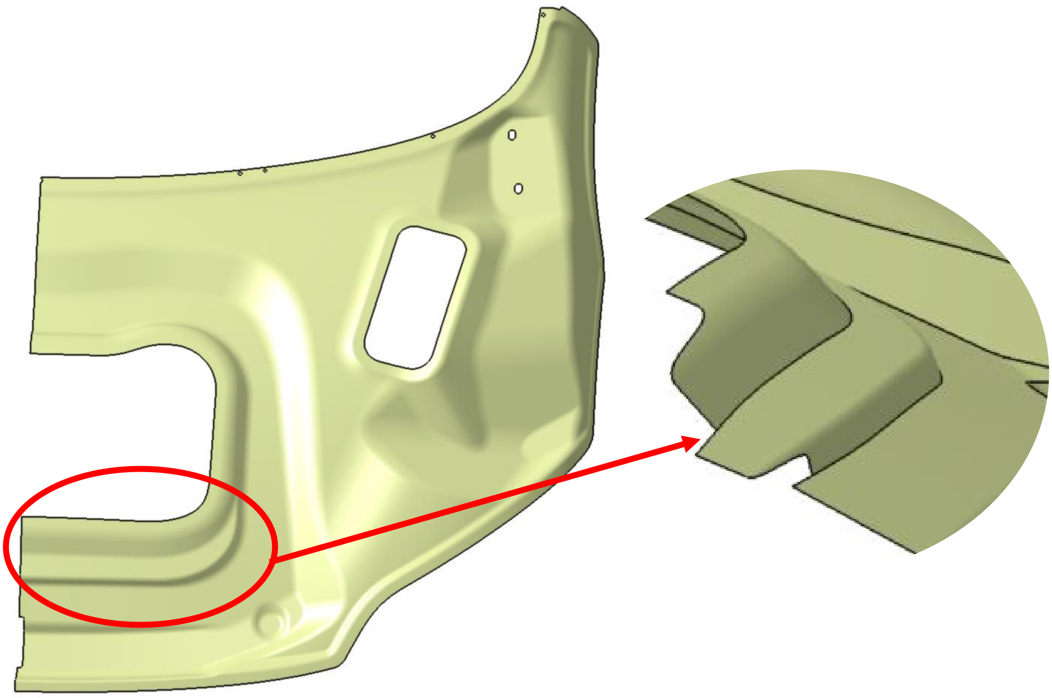

Figure 73: Aluminum Skeleton step 7

Once finished, I have symmetrized half the skeleton and I have obtained the final hood skeleton surface as in Figure 74.

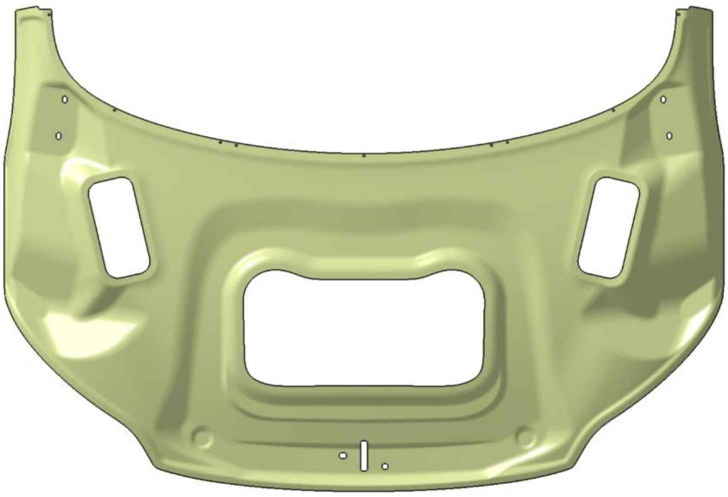

Figure 74: Final aluminum skeleton

Once the surface has been completed, we can transform it in a solid of 1.5mm of thickness as can be noted in the measurement reported in Figure 75.

Moreover, in Figure 76 we can confirm the gap leaved for the structural gluing, 0.25 mm (b); and the gap leaved for the central gluing, 3mm(a).

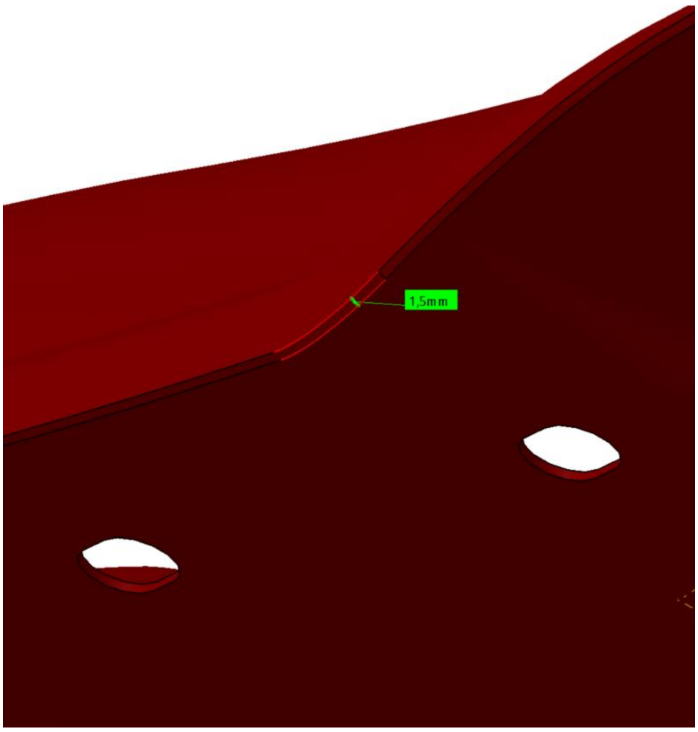

Figure 75: Aluminum Skeleton Thickness

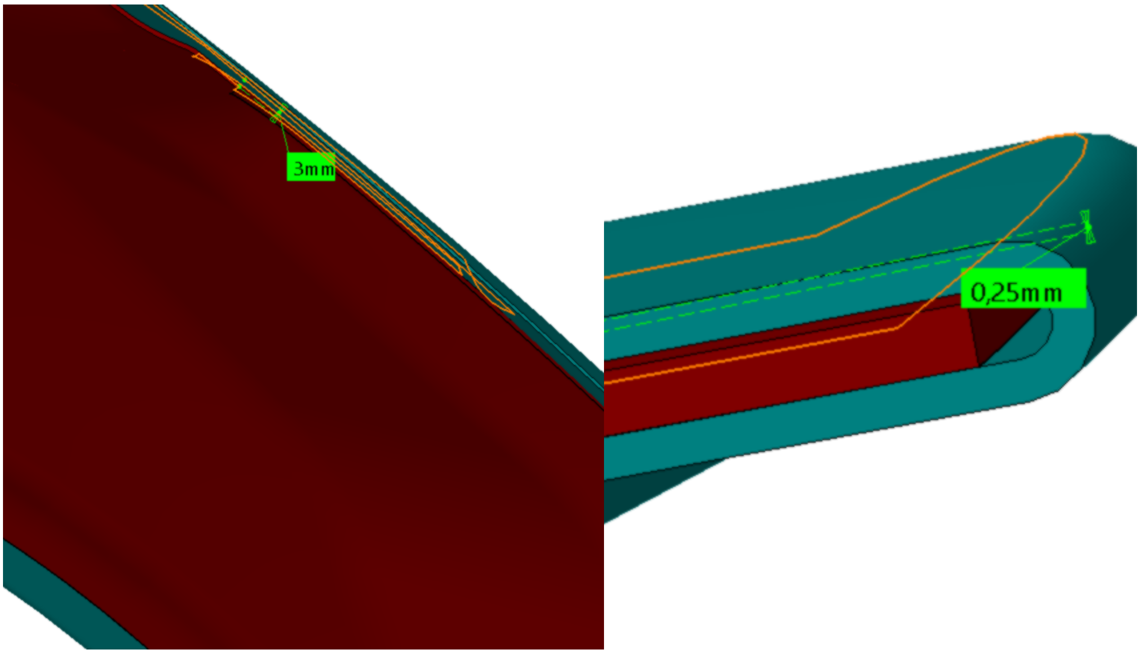

Figure 76: (a) central gluing seat (b) structural gluing seat

Having the finished skeleton, I have to project some reinforcement in the zone of the hinges and in the sone of the closure as well as the hood lock.

All the three elements that are shown in Figure 77 are made in S235J0 steel.

In particular in first row there is the door lock and the closure reinforcement, while in second row we can appreciate the hinge reinforcement.

In Figure78, we can see the whole skeleton with the proper reinforcement placed in position and also, we can notice the violet and yellow elements which identify the structural and anti-flutter glue. Moreover, in Figure 79, we can appreciate a section view which better highlights the connection among all the elements.

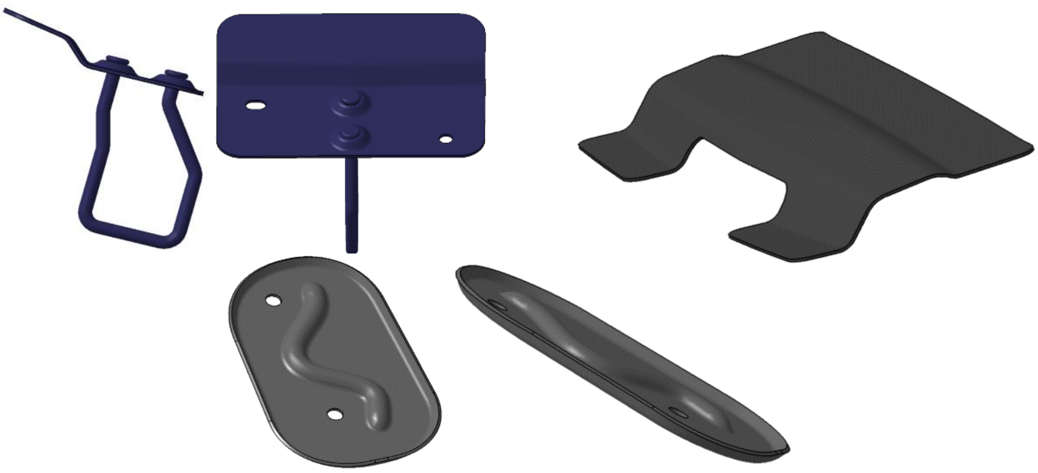

Figure 77: (a) hood lock (b) closure reinforcement (c) hinge reinforcement

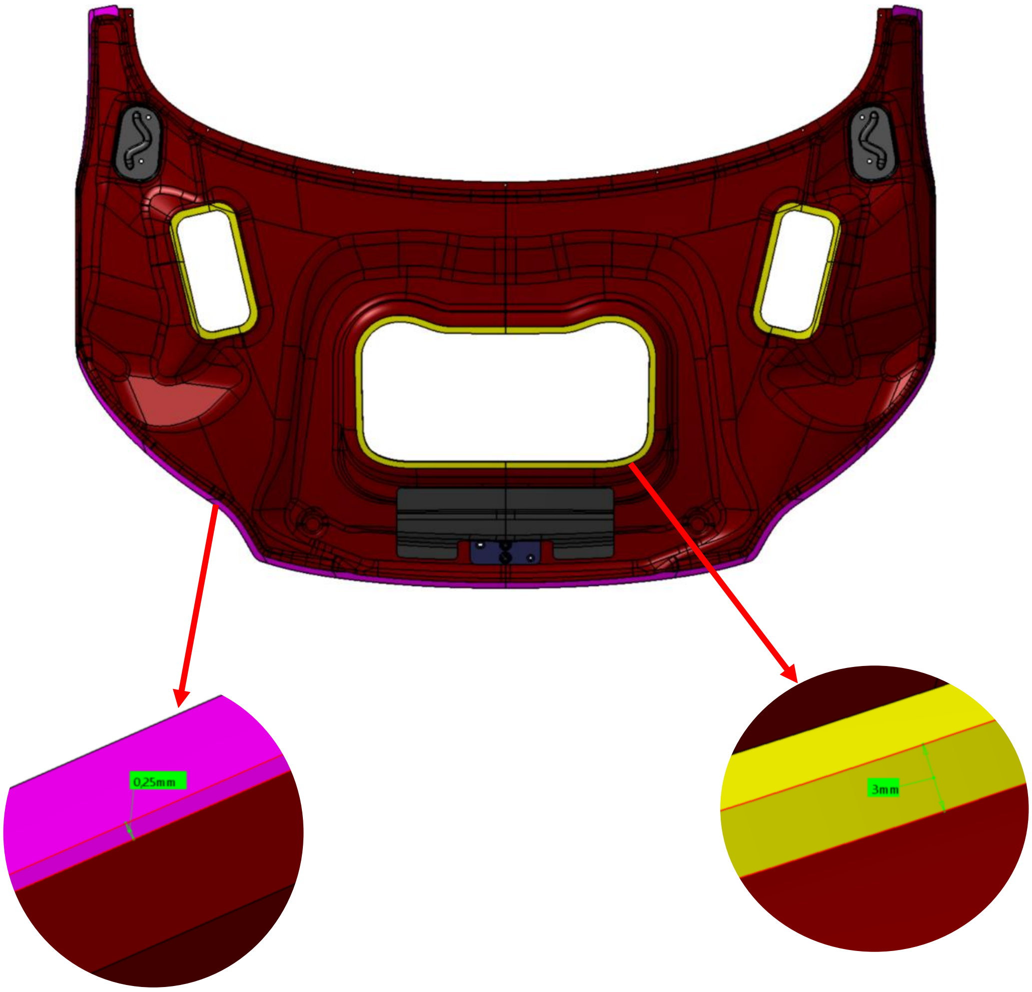

Figure 78: Aluminum Skeleton complete of reinforcement and glue.

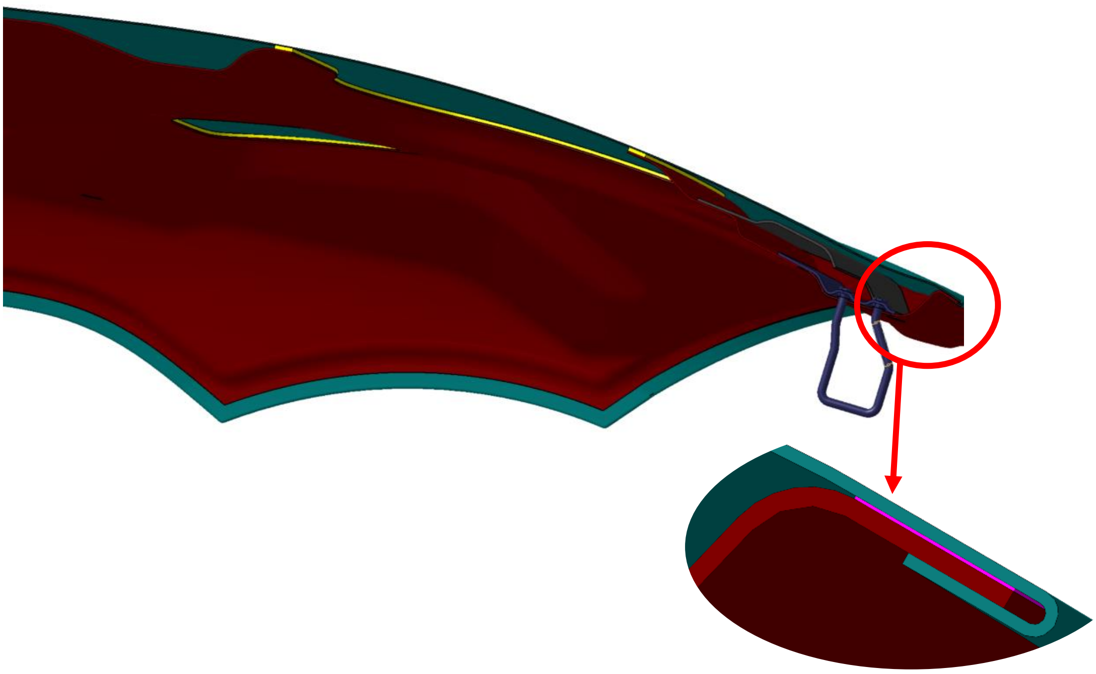

Figure 79: Aluminum Skeleton section view

CARBON HOOD

As for the aluminum one, also the design process for the carbon hood started from the skin surface. In this case, although, there were no modification and this because the carbon fiber does not need any hemming junction process, instead the glue is placed directly in the inner surface of the skin with a glue thickness of 2mm.

Moreover, also the solid created from the surface has a thickness of 2mm.

As can be seen in Figure 80, we can appreciate three zooms that highlights what said so far, that is to say the lack of any hem; while there is the flange in the upper part of the hood and that is glued to the skeleton.

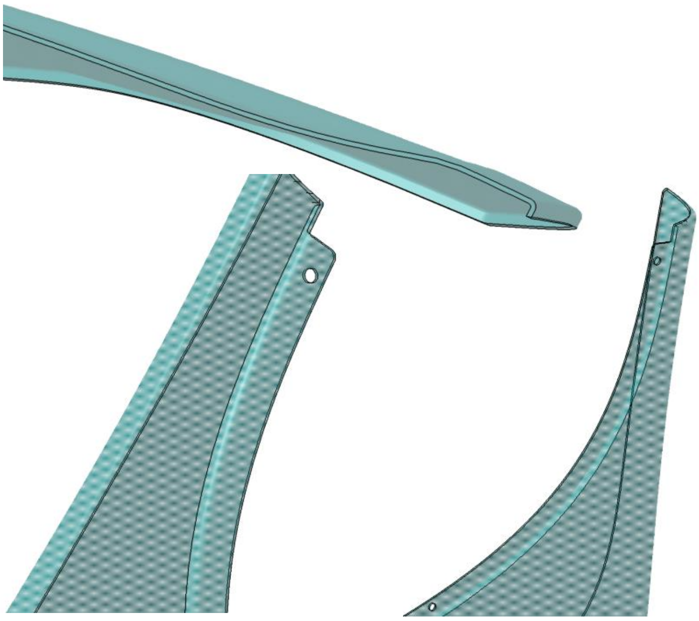

Figure 80: Carbon Hood Skin

For the development of the skeleton, I started with an offset of the internal part of the skin solid creating a first skeleton release with a flange running all around for gluing it on the skin itself; maintaining a gap of 2mm for glue between inner skin and outer skeleton. This is reported in Figure 81.

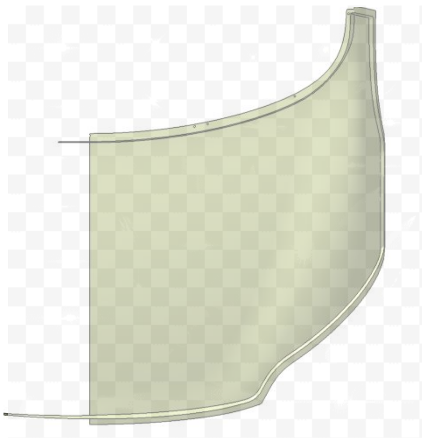

Figure 81: Carbon Skeleton step 1

Once again, considering the constraints already evaluated, the skeleton took place. In the following figures sequences, we can appreciate step by step the skeleton rise. From the central modification containing the closure interface, the seat for closure reinforcement and the seat for central gluing (Figure 82); to the second modification were the seat for the hinge reinforcement and the outer bumper has been created (Figure 83) and the final two modification for the external gluing seat comprehensive of radius for eliminate non tangencies between surfaces (Figure 84) and the one for the internal bumper (Figure 85).

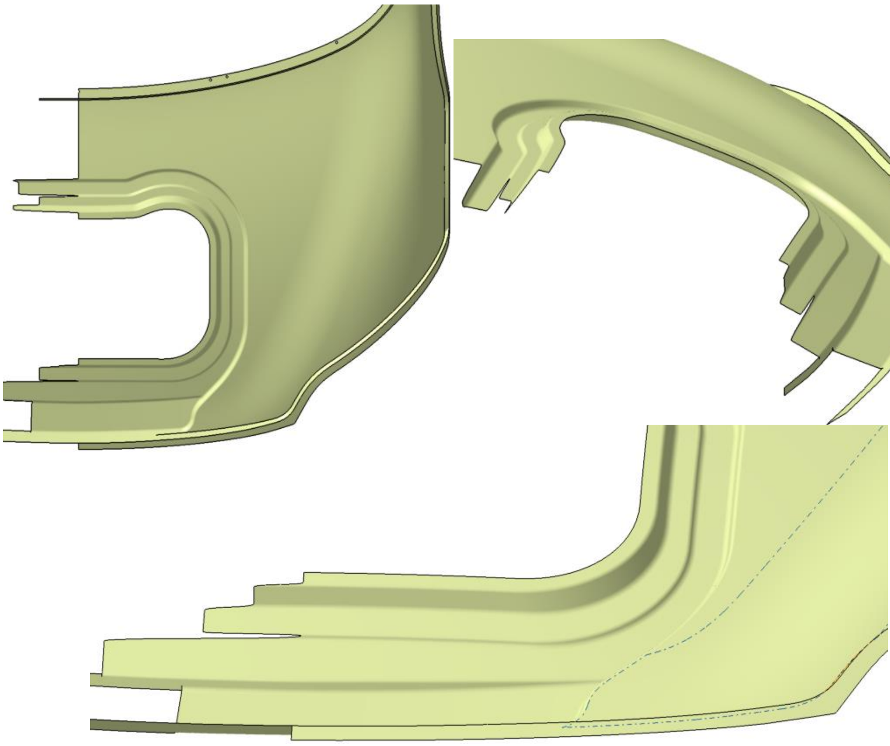

Figure 82: Carbon Skeleton step 2

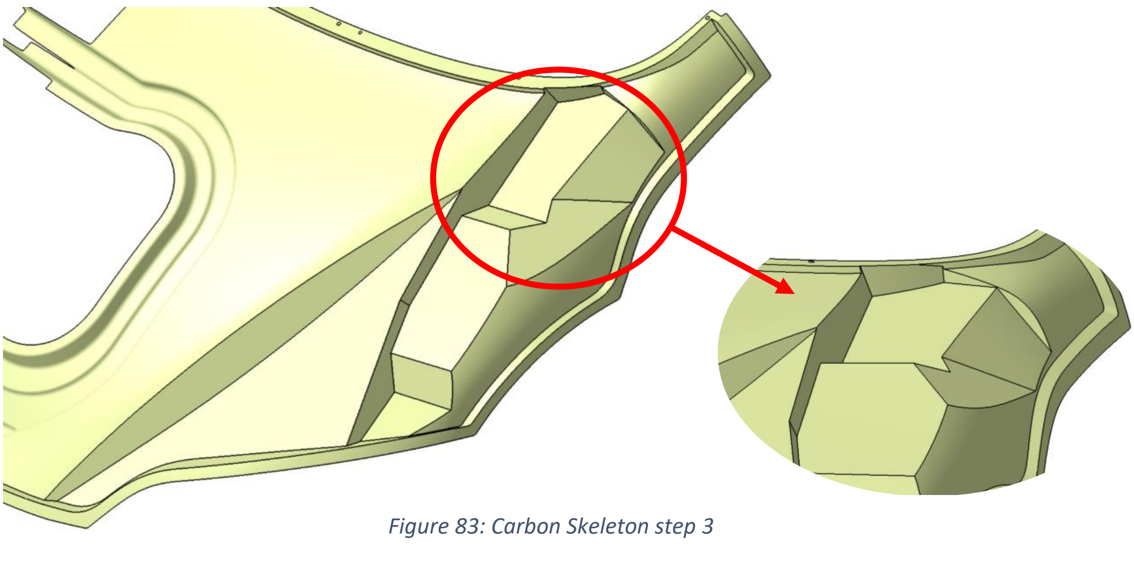

Figure 83: Carbon Skeleton step 3

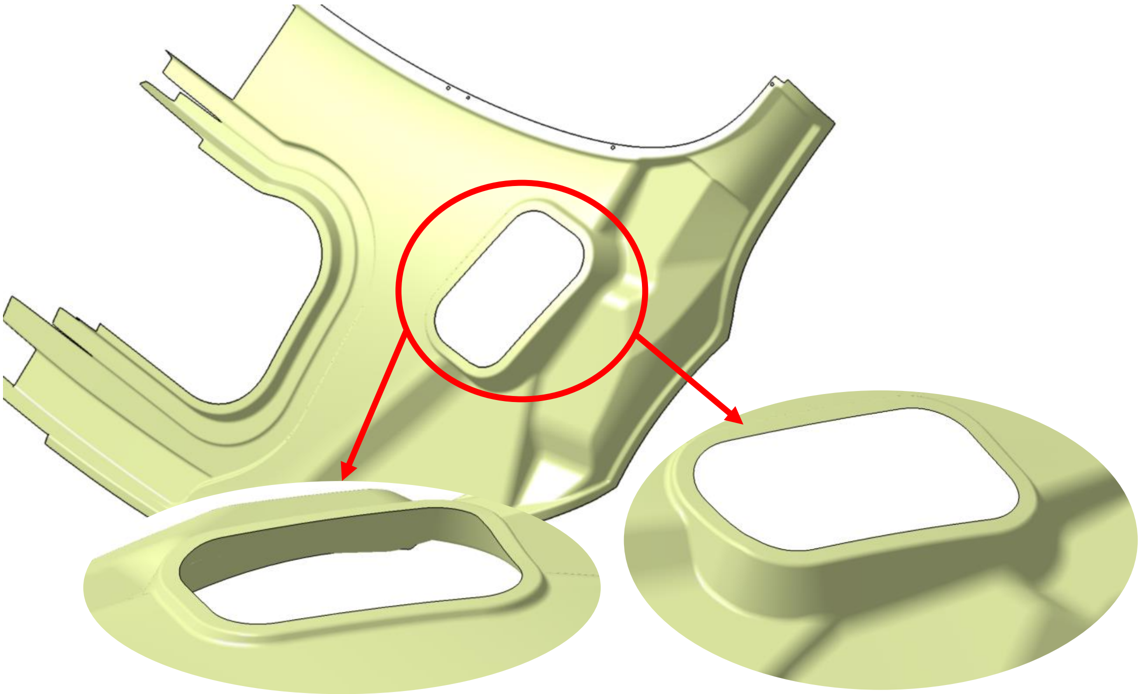

Figure 84: Carbon Skeleton step 4

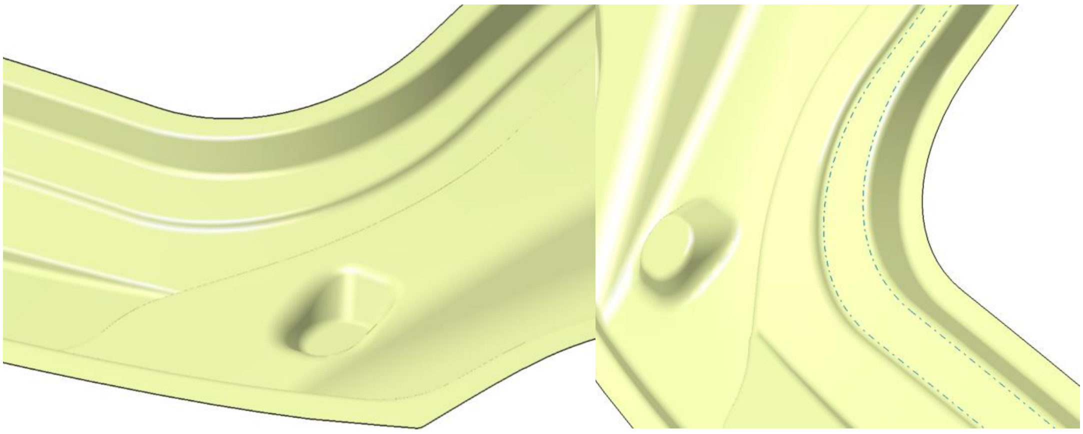

Figure 85: Carbon Skeleton step 5

Once all the modification for respecting all the given constraints were made, the final skeleton surface was made by symmetrize the existing half and the final shape is reported in Figure 86.

At this stage, the carbon skeleton solid has been created from the surface with a thickness of 1.8mm as reported in Figure 87; it worth of note that the distance between skeleton and skin solids is of 2mm, as reported in Figure 88, for hosting the glue.

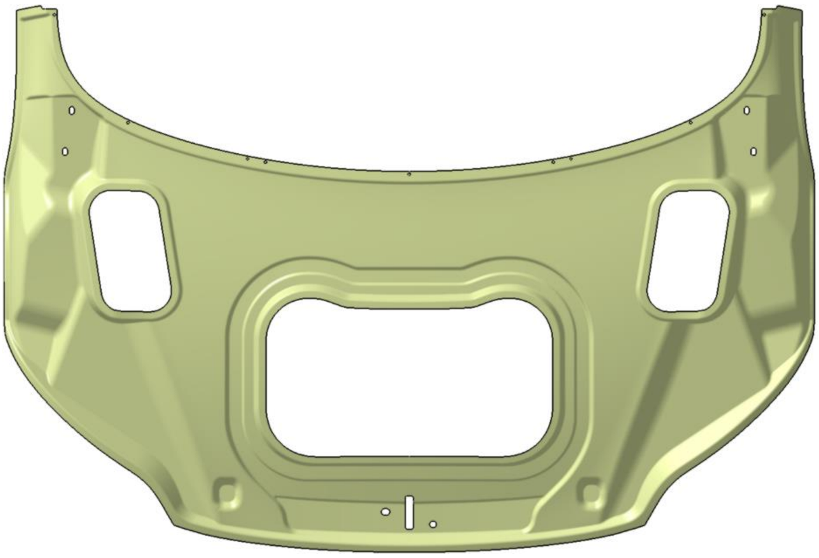

Figure 86: Carbon Skeleton step 6

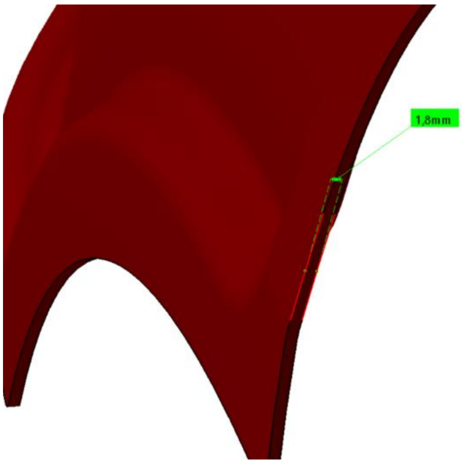

Figure 87: Carbon Skeleton thickness measurements

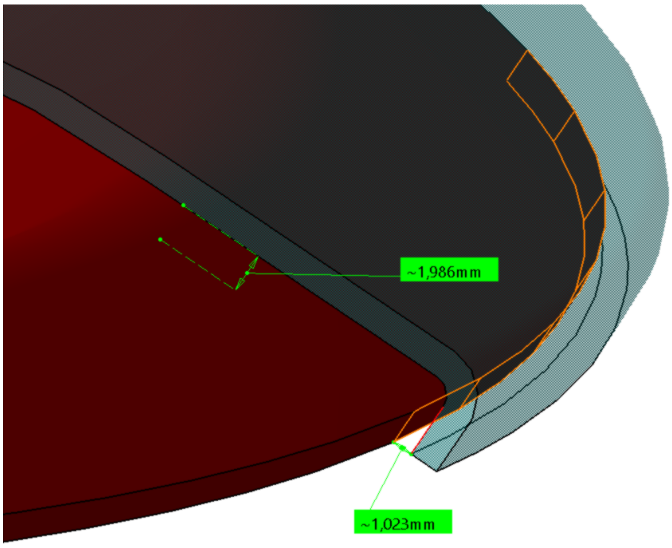

Figure 88: Carbon Skeleton-Skin Gluing gap measurement

As last commitment in this designing process I project the reinforcement of the closure, Figure 89 (a); and the one for the hinge, Figure 89 (b). While the hood lock has remained the same as for the aluminum hood.

Finally, in Figure 90, there is an entire view of the final skeleton with the reinforcement and the glue all in the correct position. Together we can see some section view and zooms which can clear make understand all the assembly of all the components designed so far.

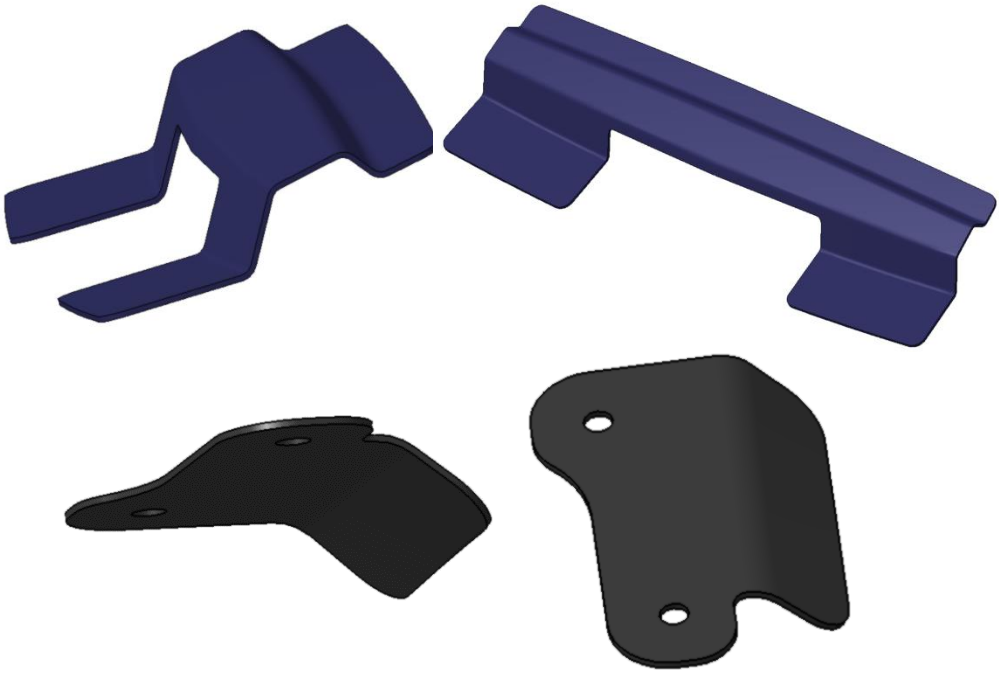

Figure 89: closure reinforcement (a) hinge reinforcement (b)

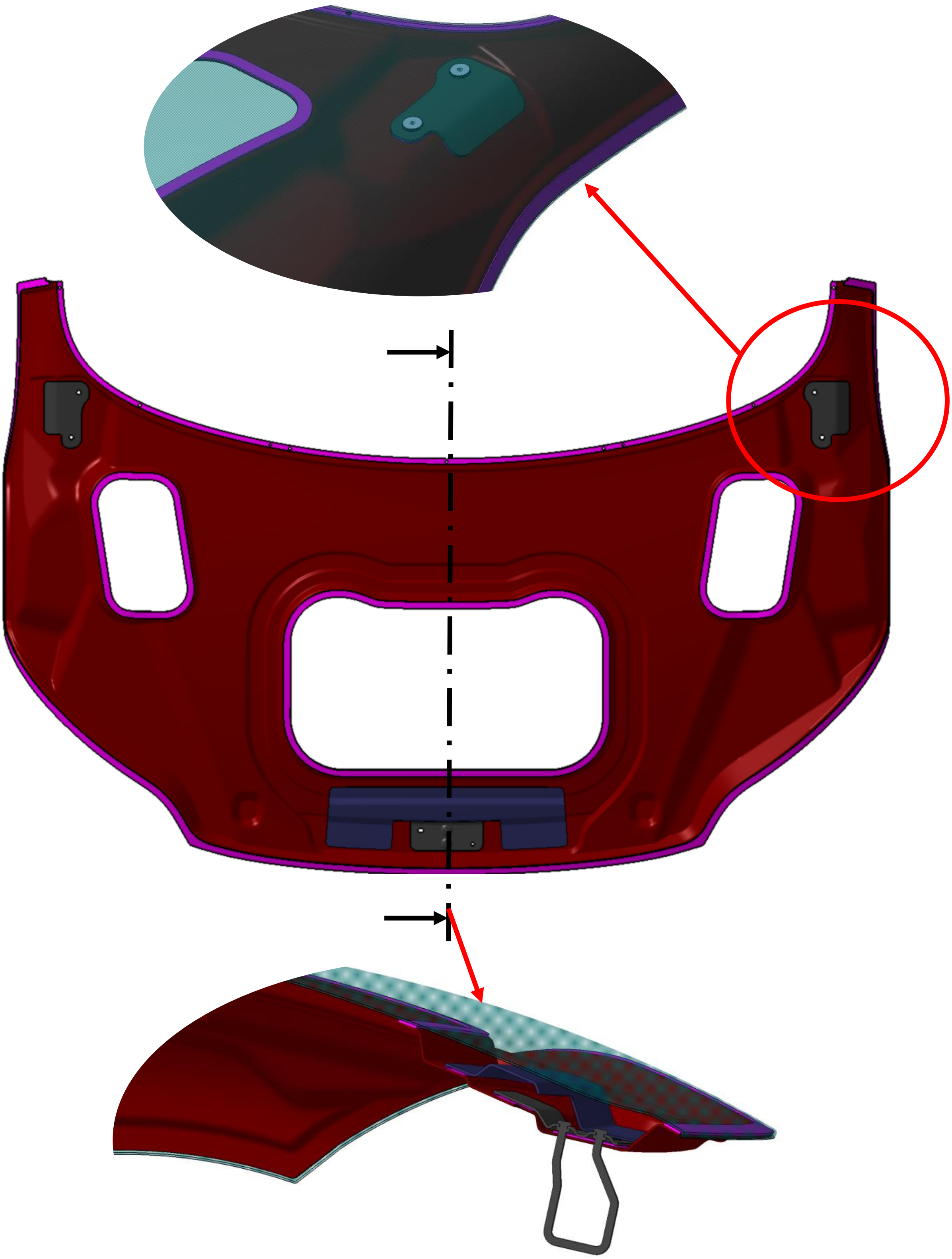

Figure 90: Carbon Skeleton final design

FASTENING METHODS

The fastening method used for joining the skeleton, the skin, and the reinforcement- to the skeleton itself, depends on the type of material to be joined and if the joining interferes with aesthetical parts.

For example, in the aluminum hood, we can use welding just in the upper part which will be cover by a seal; for the same principle, rivets can be used to fix the reinforcements and the closure, while for fixing the skeleton and the skin together we have to use glue.

For what the carbon hood is concerned, we cannot use any type of other process apart from glue.

In this section I want to talk more in deep of the method adopted in this project.

SELF PIERCE RIVETING [18]

The self-pierce riveting (SPR) process is a cold forming operation that is used to fasten two metal sheets inserting a semi-tubular rivet trough the top sheet, piercing the bottom one, without perforating it, and spreading the rivet skirt thank to a female die.

In Figure 91, we can have a representation of the SPR process.

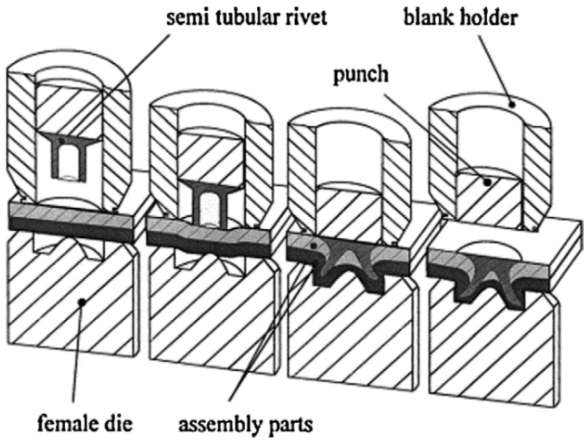

Figure 91: SPR process

Due to the fact that the process is based on a mechanical joint between the surfaces, instead of fusion of the material, it can be used on several combination of materials, apart from brittles one. For example, in my application, we use rivets to join the aluminum skeleton with the steel reinforcements and closure.

Other advantages are that the process does not need any pre-drilled hole so the process have a faster cycle time; while from a mechanical point of view, a high strength and increase fatigue properties can be achieved.

In Figure 92, I want to show some examples of the usage of SPR in my work. It is important to note that the rivets are spaced of 20mm, cause we have to allocate space for the machine which has a minimum diameter of obstruction of 18m; so, we have to guarantee to the rivet gun a flat surface on which to lean to insert the rivet that has instead, a diameter of 8mm.

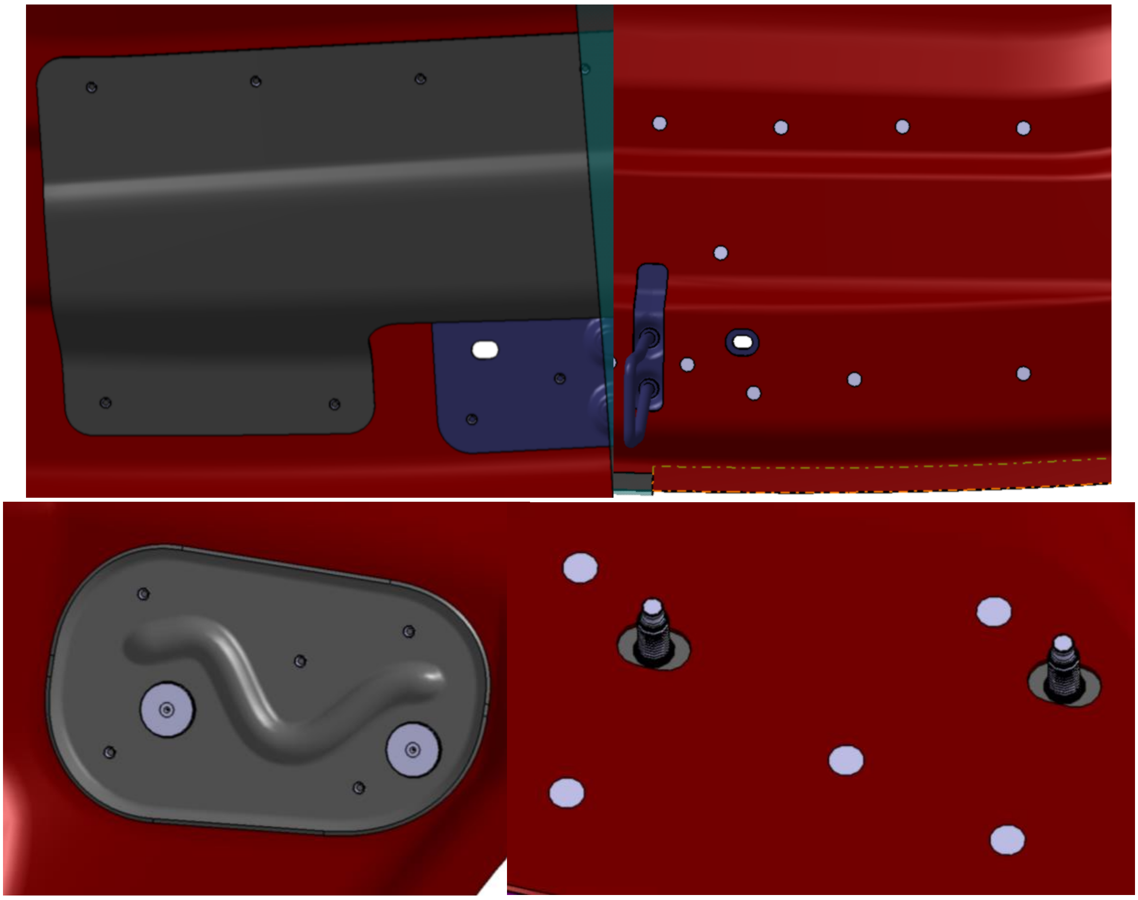

Figure 92: SPR example

SPOT WELDING [19] [20]

The electrical resistance spot welding process for joining two materials is based on the localized melting and coalescence of a small volume of material due to the heating caused by the passage of electrical current. During the process, both current and resistance changes according to the melting material.

In Figure 93, we can see a representation of the spot welding process; the water cooled copper electrodes provides three functions: the low resistance provides a pathway for carrying high current to the pieces to be weld reducing the heat losses; the high thermal conductivity provides an easy way for controlling the melted notch; they exert on the surface a high force, this produce a local deformation that is needed for create a good electrical contact in order to allow to the currant to flow.

The deformation caused by the process make it not suitable for joining of aesthetical parts; moreover, it is applicable just to a precise a limited group of materials.

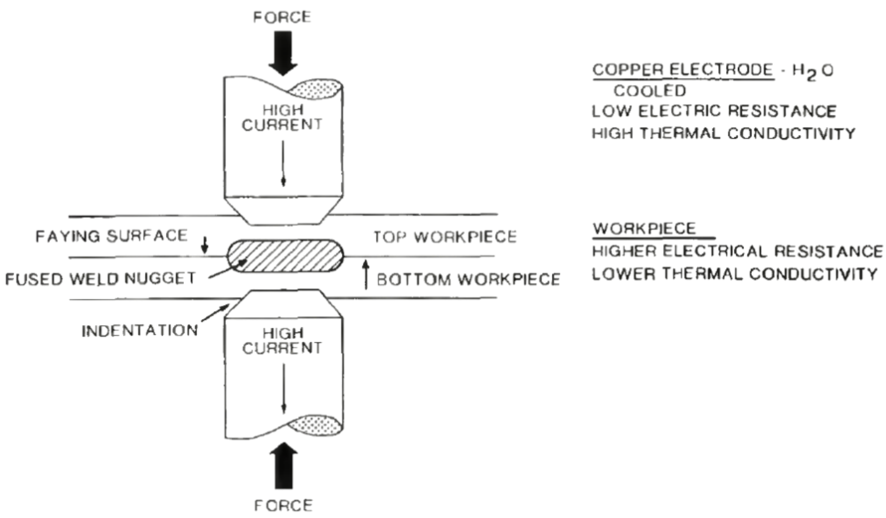

Figure 93: Spot Welding process

In Figure 94, there is an example of the usage of spot welding in this project. In particular, it has been used for joining the skin and the skeleton in the upper part of the piece; the only reason for using spot instead of simple glue is because that part will be covered by a seal or by a plastic aesthetical cover.

In the figure, the spots are represented by a red cylinder of 5mm of diameter; also there, the spots are spaced of 20mm for allocating enough space to the welding gun to guarantee a plane surface which has a minimum diameter of obstruction of 16mm.

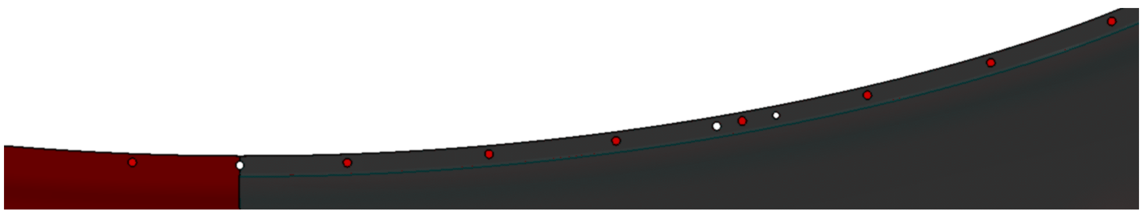

Figure 94: Spot Welding example

STRUCTURAL AND ANTI-FLUTTER ADHESIVES [21] [22]

Nowadays a well-used practice is to use welding for joining two panels although it presents some problems like the difficulties in joining two sheets of different thickness or the thermal influence on the welded area that can cause aesthetical damages.

Using the bonding technologies, we can avoid these problems and we can have other significant advantages such as the reduction in the weight of the car, preservation of the zinc layer and high quality of appearance.

Main advantages of bonding methods are that they can be used for joining distinct types and thickness of materials; for example, we use it between two aluminum panel, between two carbon panel and between a carbon and a steel part. In Fact, another advantage is that we can use glue where any other fastening method cannot be used; for example, in carbon hood, the only feasible way of joining two carbon panel in our application was gluing them together as well as the only way of joining a carbon skeleton to the aluminum support was to glue them together.

There are several types of adhesives, and the usage is strictly link to the material to be joined and to the function for which the adhesive is used; in this project there are two types of adhesives used for two different purposes: structural glue and anti-flutter glue.

The structural adhesive is that type of adhesive used when a strong bonding is required, mostly used between external panel and their skeleton in aluminum part or for any junction in carbon part. It is high strength bonding, and it cures when exposed to high temperature in the paint oven.

The second type of adhesive that I have adopted in my project is the anti-flutter adhesive which is used to enhance the stiffness of the suspension of parts and outer parts and to reduce vibration and noise emission of these parts; moreover, this type of adhesive must compensate tolerances, fill up wide gaps and should have low shrinkage and low modulus. Anti-flutter adhesives are rubber-based adhesive sometimes modifies by epoxies.

In Figure 95 and Figure 96, there are some examples of the adhesive used, it is worth to say that in purple we indicate the structural adhesive that in aluminum hood as a thickness of 0.25 mm while in carbon hood as a thickness of 2mm; while in yellow we use the anti-flutter adhesive used only in aluminum hood with a thickness of 3mm.

For all the three types of adhesive, the layer width is 20mm in order to guarantee a solid junction.

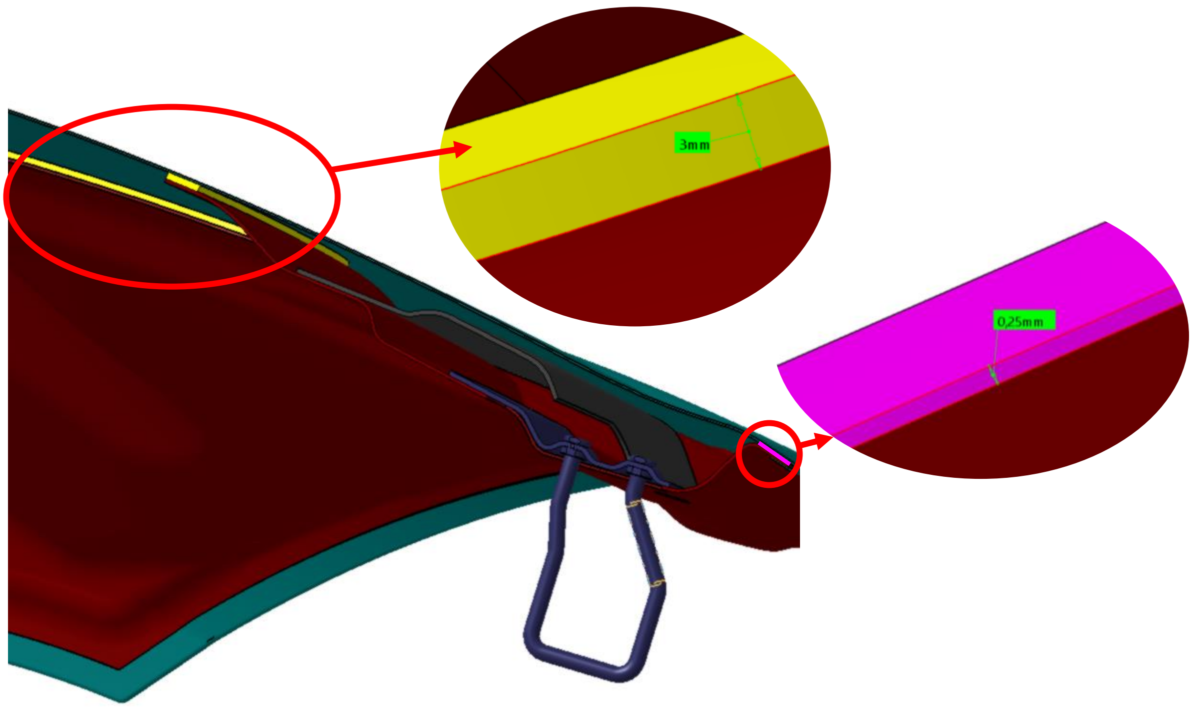

Figure 95: Aluminum Hood's structural and anti-flutter adhesive

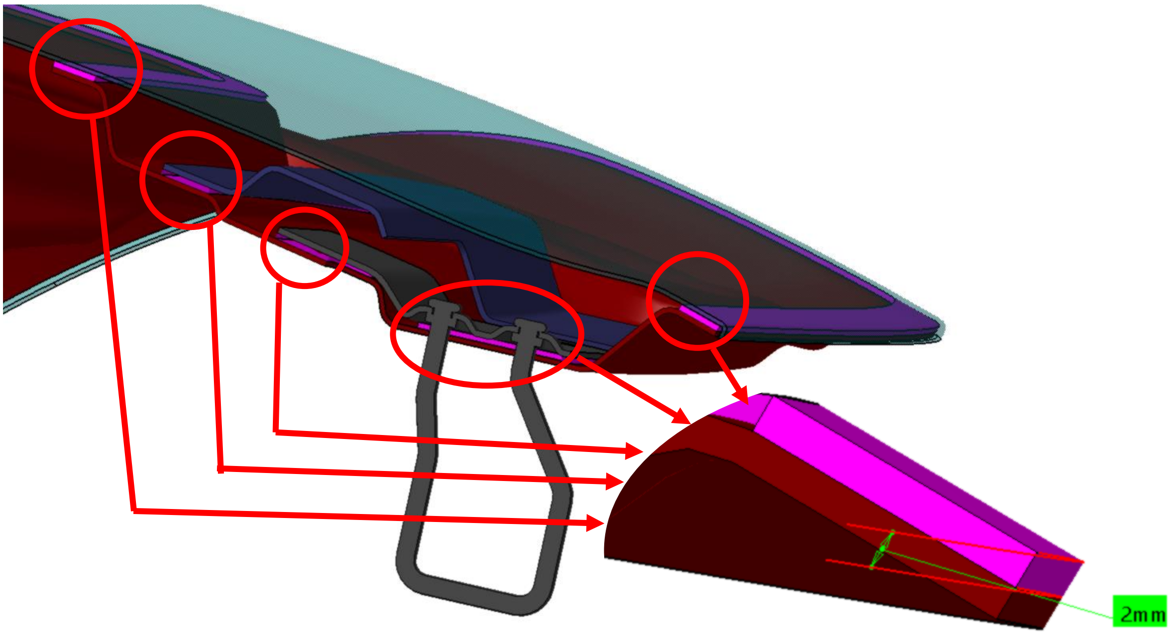

Figure 96: Carbon Hood's structural adhesive

FINAL CONCLUSION

ALUMINIUM vs CARBON DESIGN DIFFERENCES

The reason why this thesis was thought, was to highlights which are the differences in the development of the same component which has to be produced in two dissimilar materials: aluminum and carbon.

To conclude the work done, I want to show all the differences with practical example; in particular, I want to talk about the action made in the design and the reason why I had to make those choices.

First of all, I have to recall some concept, already explained, about the manufacturing processes of the hood in both of materials.

For the aluminum hood we have to keep in mind that the production process starts from a metal sheet of the desired thickness which is inserted in a press and undergoes to a drawing process between two dies which impress the final shape.

One of the biggest constraints in producing an aluminum part; is that the final part has to have very rounded shape, with walls as far as possible from the vertical position and so with big angles of slope, big radius and avoiding any cup-like shape. The reason is that we have to guarantee the flowability of the metal sheet inside the press, avoiding that a too sharp shape will cause a high residual stress bringing to a tearing into the final piece.

For what the carbon hood production process is concerned, we have less constraints given by the production. This because the carbon fiber, which is much more modulable respect to aluminum, is deposited inside a mold layer by layer and then liquid resin is inserted, between layers, before the curing process occurs. Once the fiber has been properly adapted to the mold shape, the product is compacted by using a negative mold or vacuum.

It is easy to understand that, using this material give less problem in production and give less constraints in design stage.

By comparing side by side, the two final hood, as in Figure 97, we can identify some regions that better can clear any doubt about that difference.

Knowing that in the figure below we have the aluminum hood on the left and the carbon on the right; in the blue, green, and yellow highlighted zones we can see that in the left one I have decided to reduce as much as possible the steps up and down that the aluminum sheet has to follow and this to improve the flowability of the metal sheet inside the press. Opposite logic has been applied to the carbon hood where a sharper shape has been adopted.

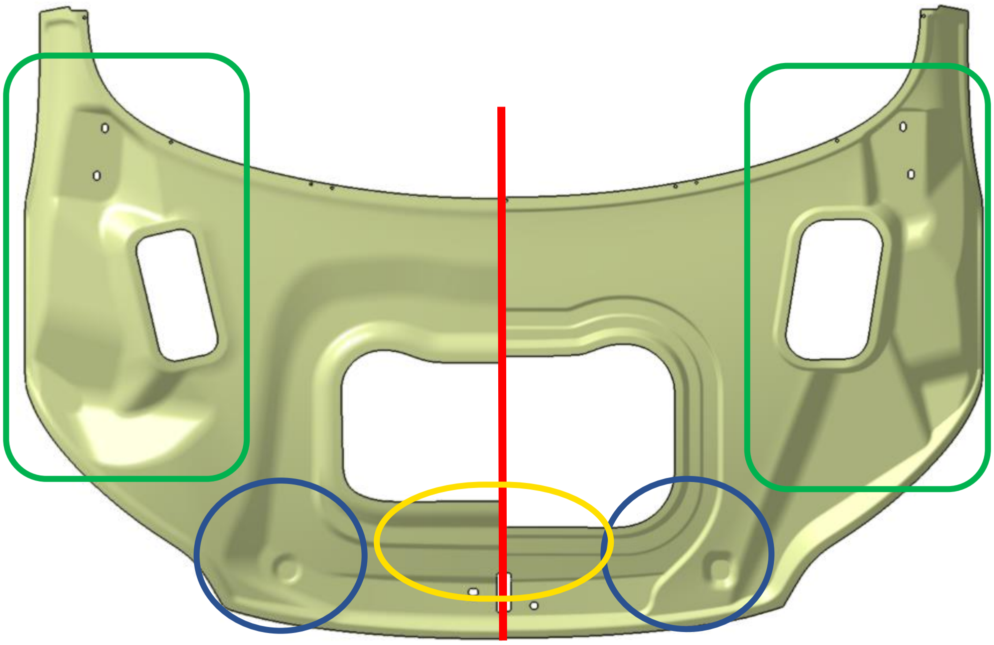

Figure 97:complete comparison of aluminum (left) and carbon (right) hoods.

Those differences can be easily seen in the Figure 98, where a zoom on the zones highlighted in Figure 97 has been made.

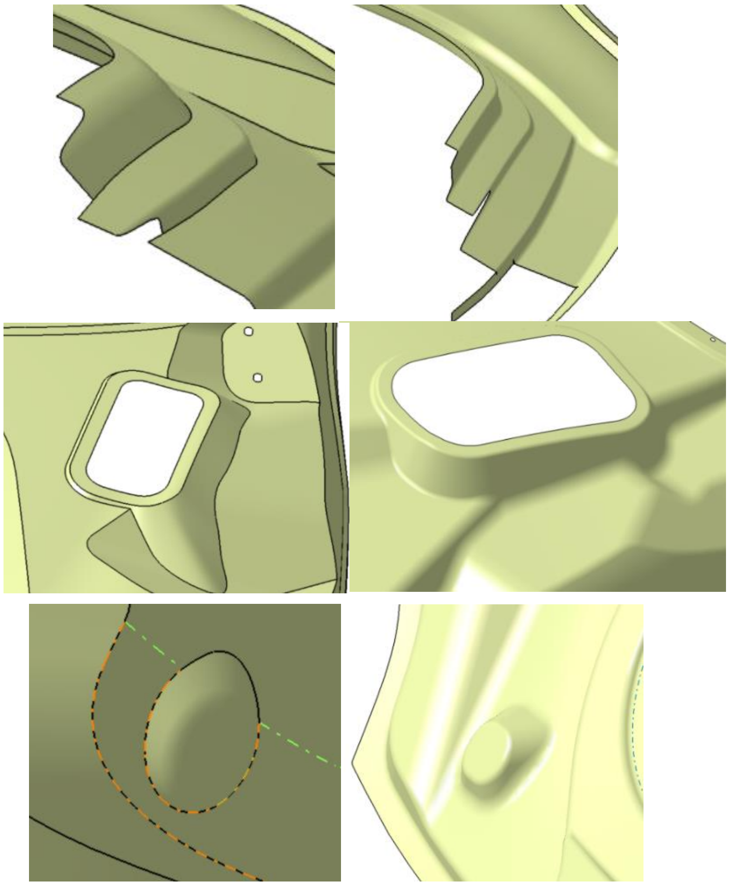

Figure 98:design differences one between aluminum (left) vs carbon (right)

Other differences in the two projects are the different thickness of the parts given by the type of material and the ability to support the given stress. In fact, for a target stress to be achieved, the carbon part has to have a higher thickness respect to the aluminum one. In particular, the thickness of the aluminum skeleton is 1.5mm while the one for the carbon skeleton is 1,8mm.

Last difference can be found in the fastening methods; in fact, if in aluminum skeleton we have a wider choice; according to the case we can adopt welding, rivets, or glue; in carbon skeleton we have just the possibility of gluing two parts together. Moreover, also considering the gluing, several types of glue are used for the two materials with different properties and layer thickness.

An aspect that is particularly important in the comparison between the two is the weight reduction between the parts. Starting from the consideration that the design has been developed in order to fulfill to physical constraints to the hood final shape that has to be identical in both the skeleton, considering the minimum thickness adopted to comply with stress requirement, we obtain an aluminum skeleton with a volume of 2411,91 cm^3 and a CRFP skeleton which has a volume of 2822,25 cm^3.

Despite this increment in volume in the latter, according to the value of density of the two material that have been presented in the dedicated chapters, the weight of the two skeleton is 6,512 Kg for the aluminum one and 4,233 Kg for the carbon fibre-reinforced one, with a reduction of almost the 35% percentage of the final weight.

This value was compatible with the values reported in the literature which foresees a reduction of about the 40% of the final weight for a piece produced in aluminum and carbon fibre-reinforced composite; the difference can be related to different type of those materials considered in the literature respect to the case of study.

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