POLITECNICO
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CORSO DI LAUREA MAGISTRALE IN

AUTOMOTIVE ENGINEERING

MASTER'S DEGREE THESIS

PLASTIC COMPONENTS ANALYSIS AND EVALUATION FOR WEIGHT REDUCTION APPLICATION

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A TUTTI QUELLI CHE CI HANNO CREDUTO

Contents

ABSTRACT

This thesis was developed in collaboration with Martur Fompak International, a leading Turkish company in the production of seats and interiors for cars, present in Italy with a production facility and engineering, research and development offices.

Given the recent regulations on CO_2 emissions to which the automotive industry must comply, a possible action to do this is to reduce the weight of the car. The main objective of this thesis is, therefore, to find different strategies to reduce the weight and the contribution that each can produce, with the possibility of obtaining an overall reduction of 10% on the analysed components.

After limiting the area of intervention to the main plastic component of automotive interiors, namely the dashboard, the first part of the thesis focuses on the materials employed to manufacture the different components and on polypropylene materials with lower density. It is important to underline that the research for different materials was carried out taking into account also the information received during meetings with suppliers. This research for alternative materials has confirmed the criticality of obtaining acceptable aesthetic results with polypropylene materials capable of guaranteeing a substantial weight reduction.

To improve the results obtained, the attention has been shifted to the moulding processes and the opportunities offered by the application of microcellular foaming to the production of components. Several options have been taken into consideration: chemical foaming agents, elements that when mixed with the polymer generate the gas when the activation temperature is reached, and patents that exploits physical foaming, MuCell® and Foam Microcellular Moulding Process® (FMC).

The three solutions identified to obtain a weight reduction greater than the objective will be subjected to moulding tests to confirm the feasibility and applicability from a technological point of view.

About Martur Fompak International

This thesis was developed in collaboration with Martur Fompak International, a Turkish company belonging to the Üstünberk family group. The company operates in the automotive sector and its core business is the production of seats, fabrics and plastic components for car interiors (dashboards, door panels, sun visors, headliners, parcel-trays) for the main automotive industries.

Founded in 1986 in Bursa, Turkey, the company has now two Headquarters in Istanbul and Paris and counts 16 offices around the world and 23 production plants in 7 nations over 3 continents, with more than 7000 employees.

Martur Fompak International is present in Turin, with a production facility and engineering, research and development offices, and in Salerno with an advanced warehouse. The Turin office was born in 2003 as an engineering and development office with 8 employees and today, with the new plant for seat assembly in Grugliasco, an increase of the staff is expected, which is supposed to reach about hundred-thirty units.

1. Introduction

1.1. Legislation about CO_2 emissions

Since the 1990s the European Union has undertaken actions to promote pollutants emissions reduction, also known as greenhouse gas emissions (GHG) and after some years from the first regulations results can be appreciated. In particular it is possible to highlight that emissions from means of transport, that are characterised by three principal pollutants (SO_x, NO_x, and particulate), are diminishing considering the period from 2000 until now, showing the effectiveness of policies undertaken thus far.

In April 2019 the European Parliament and other international organisations signed a regulation named *"Setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/2011"* (Regulation (EU) 2019/631) stating the new limitations of carbon dioxide (CO_2) manufacturer's fleet mean emissions for 2025 and 2030 lowering respectively by 15% and 31% the 2021 limit. Considering the New European Driving Cycle (NEDC) as reference to evaluate vehicle emissions is possible to represent the historical data and European Union standards: the target for 2025 will be 81 g/km of emitted CO_2 while the next objective for 2030 will be 59 g/km as represented in Figure 1.1.

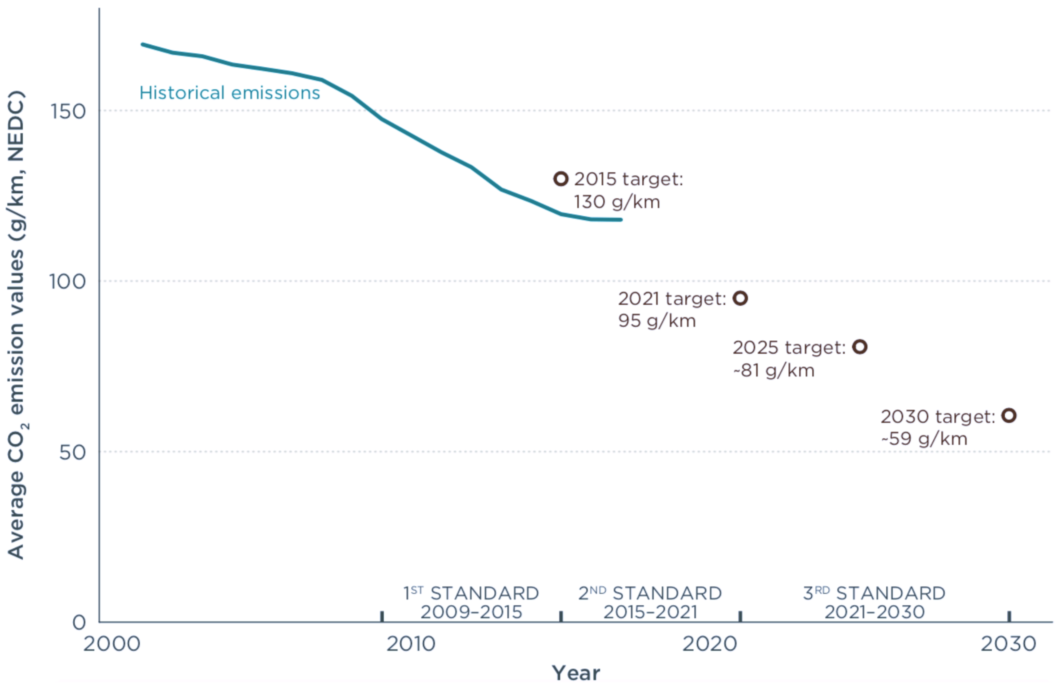

Figure 1.1. Historical emission average CO_2 emission values and new European Union emission target

It is truly significant to consider some elements that influence emissions, first of all the corrective factor for the mean mass in running order (utility parameter) applied to correct the limit of permitted emissions for each manufacturer. Figure 1.2 shows the different car makers CO_2 emission limits based on average mass on running order, these limits ranges from 91 g/km for FCA to 102 g/km for Daimler. (The International Council on Clean Transportation, 2018)

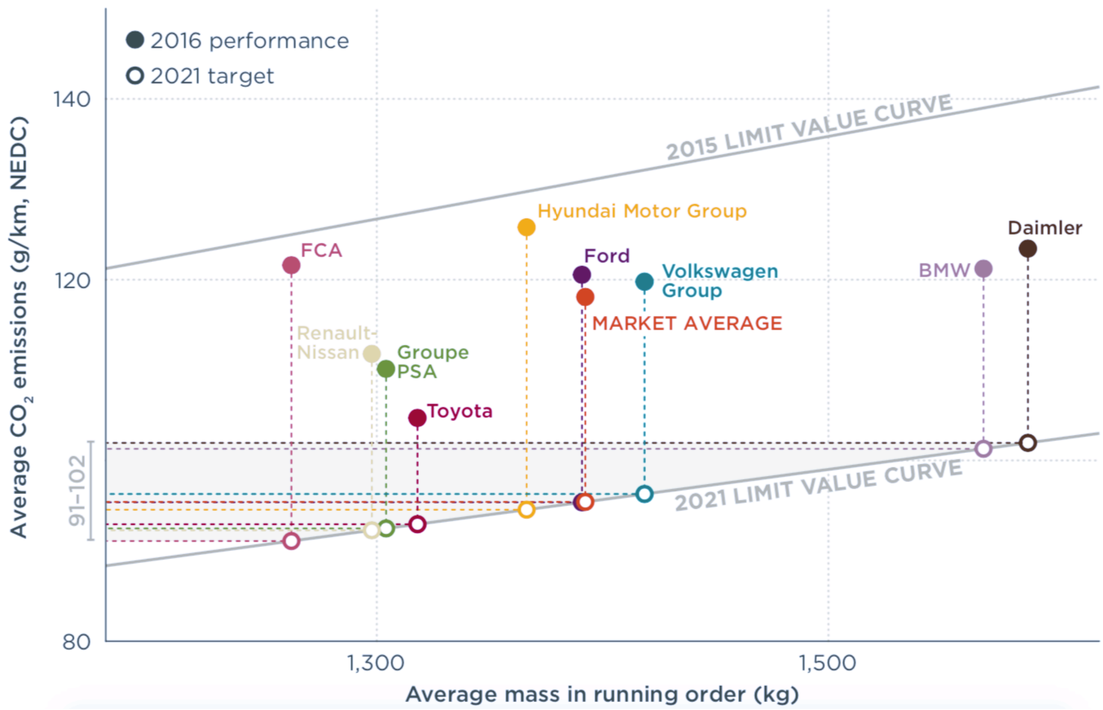

Figure 1.2. Effect of average mass in running order on 2021 CO_2 emission limits

This corrective factor is somehow considered a discouraging parameter with respect to vehicles light-weighting, since a heavier car fleet denotes a higher CO_2 emission target for that manufacturer allowed by regulations. This problem has been considered by the legislator contemplating different options but finally choosing to review the current evaluation of the parameter, with effect from 2025, considering the vehicle's mass specified in the Worldwide Harmonised Light Vehicles Test Procedure (WLTP).

WLTP test cycle, that will be the new CO_2 emissions evaluation scheme starting from 2021 although already introduced since 2017 side to NEDC, will definitely influence the targets for the different car manufacturers introducing a level of uncertainty. WLTP test cycle is different with respect to the NEDC's test cycle, all the characteristic parameter of the driving profile and test conditions (acceleration rates, use of accessories, driving length, etc.) will lead to a review of emissions target to be achieved by car manufacturer towards higher levels because WLTP wants to be more representative of real driving profile.

In Figure 1.3 is possible to appreciate that 95 g/km target for 2021 is based on NEDC cycle and after this point the limitations will be applied with reference to the WLTP starting point in 2021. It is also possible to note that it is not indicated a figure for the new reference because the uncertainties derived from the new test cycle introduction; the only objective identified is a 37,5% reduction from 2021 target to 2030 one.

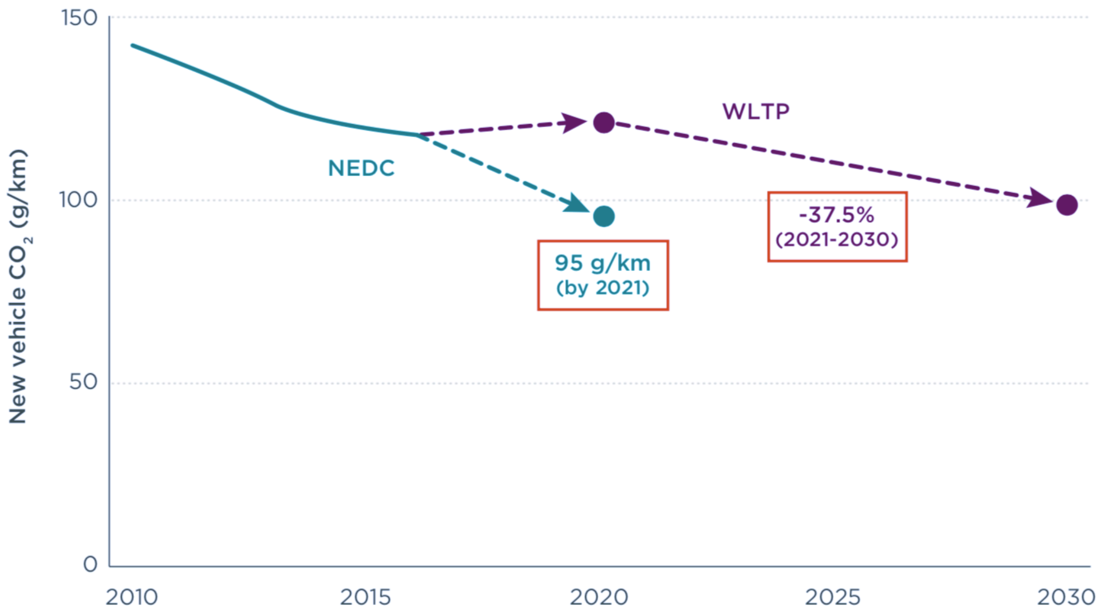

Figure 1.3. Emission limits based on NEDC cycle in 2021 and from 2021 beyond on WLTP

An important aspect for car manufacturer will be fact that those exceeding the prescribed limits, not meeting the emissions target, will be fined of € 95 per produced vehicle for every gram per kilometre by which the car manufacturer's fleet average emissions exceeds its target.

European Union is not the only nation that has stepped toward carbon dioxide emissions limitation, also other countries in the world are active in this regard. As Figure 1.4 shows European Union target will be approximately 80 g/km similarly to U.S. and Canada with 99 g/km in 2025, the central point is the global trend to reduce emissions. Nevertheless this picture of future tendencies is not taking into account any innovations or perturbations from real world.

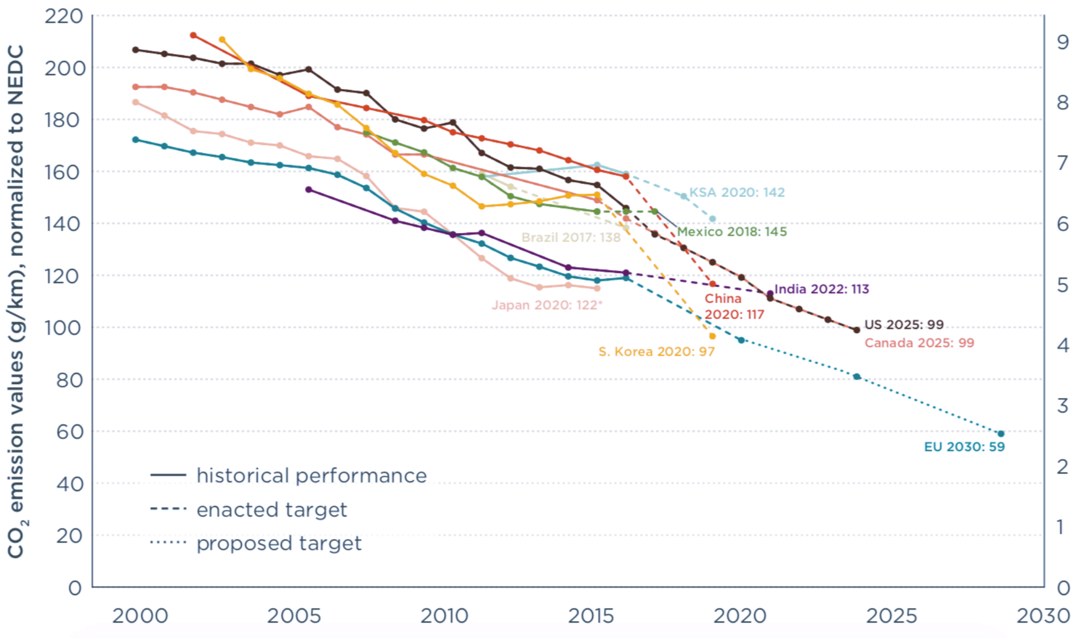

Figure 1.4. Global CO_2 limitations for passenger cars

1.2. Strategies to reduce emissions

All automotive Original Equipment Manufacturers (OEMs) are facing the changing environment of emissions regulation working hard on several aspects of the vehicle. The technologies developed up to now enable an improvement of the overall result in terms of emission and fuel consumption reduction; these two problems must be faced together and in a global way in order to have a correct approach studying the energy consumption through the whole vehicle life cycle. Considering the vehicle from production to end-life provides a more accurate picture of the emissions balance resulting from the changes implemented to improve the emission performances of the vehicle and the emission produced during the operating life of the vehicle.

1.2.1. Conventional drivetrain optimisation and new powertrains

A method to reduce pollution is an optimisation of existing technologies regarding the powertrain: downsizing, combustion's efficiency improvement and internal frictions reduction are some examples of interventions that can be included in this approach. These actions are very important because in the foreseeable future, gasoline and diesel engines will continue to dominate the scenario of powertrain market shears considering the different energy resources, as it is possible to see from Figure 1.5.

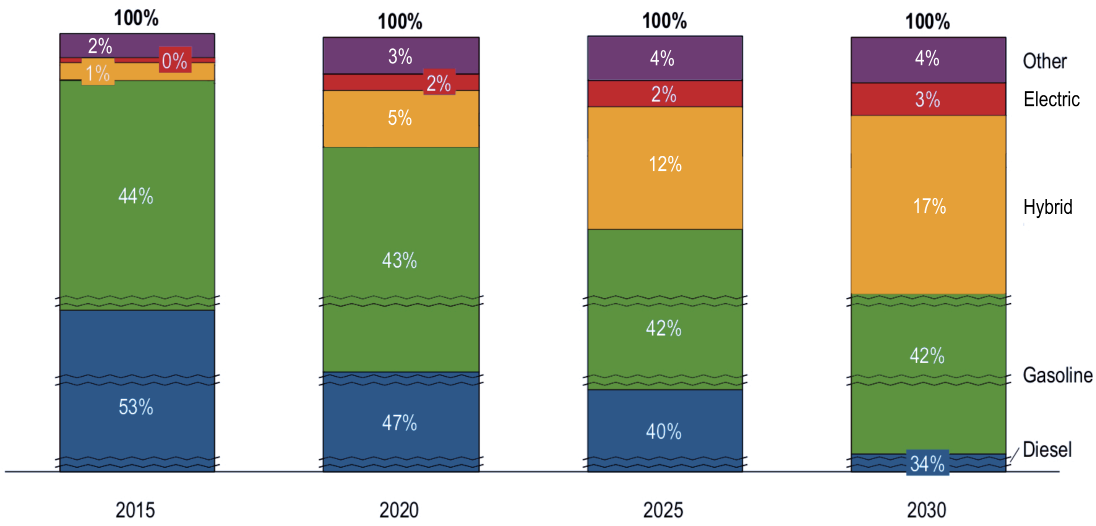

Figure 1.5. Possible scenario for market shares percentages of future fuels/power plants

A step forward can be taken implementing and developing new powertrain technologies, exploiting the opportunity given by the diversification of energy resources such as electrification or fuel cells. This approach comprehends Battery Electric Vehicles (BEV), Hybrid Vehicles and non-conventional fuels, which constituents are not strictly hydrocarbons. Each powertrain has its implications with positive aspects and drawbacks that will be improved with the technology development leading to a possible the diversification as the one proposed in Figure 1.5. This diversification of energy sources is going to mitigate the strong dependency of current vehicle fleet on oil and its derivate guaranteeing at the same time a more sustainable mobility for the upcoming years.

1.2.2. Efficiency improvement

A different approach is represented by the possibility to improve the efficiency of the vehicle lowering the energy required for motion. The results and knowhow deriving from this methodology are applicable both to vehicles with traditional powertrains and to vehicles with new powertrains thanks to the range extension implications, considering the critical point about the total amount of energy that can be stored on board. Figure 1.6 splits the energy requested for motion into two curves: rolling resistance power (indicated with the number 1), aerodynamic drag power (indicated with the number 2) and the overall resistance to motion given by the sum of the two (indicated with the number 4).

Different activities can be part of this approach, as an example aerodynamic improvements comprehend actions aimed to aerodynamic drag reduction (aerodynamic drag is the force that opposes to the vehicle body motion in the air). These actions have a greater influence on high speeds (generally above 80 km/h) where vehicle's drag is dominating the overall power required for motion as shown in Figure 1.6. Aerodynamicists are working on drag reduction since the '70s with remarkable results, thanks to the parallel work of computational fluid dynamics (CFD) and wind tunnel experiments, lowering the drag coefficient (C_x) from 0,5 to 0,25 that means 25 g/km of carbon dioxide less considering the NEDC cycle. (Daimler AG., 2019)

Another important activity is the rolling resistance reduction: it is possible to see from Figure 1.6 that its contribution is greater at lower speeds with the consequence of impacting more during urban driving, it is one of the better ways to obtain fuel consumption reduction. This type of energy dissipation is originated from tire damping but as they are complex objects each intervention is going to modify their performances as whole. This means that the optimisation must be carried out as an overall activity that is going to consider the tire as a whole.

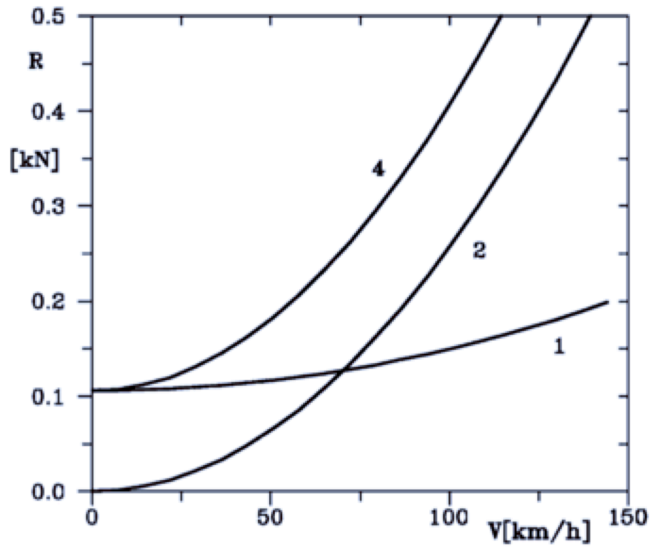

Figure 1.6. Energy requested for motion

Light-weighting is an other activity that can be applied by carmakers to reduce emissions and fuel consumption, different studies showed that a car weight reduction of about 10 kg can lead to a general cut of 1 g/km of CO_2 emitted. A decrease in vehicle mass can be significant for the reduction in energy required during acceleration as well as for rolling resistance reduction leading to an improvement of urban driving fuel consumption and emission. The overall trend in past years, despite these considerations, was an increase in weight due to the strict safety requirements (both passive and active) as well as to customer requirements (larger cars) but recently this trend has been inverted. A general idea highlights that better results can be obtained trying to optimise each component saving some grams and not reducing few components weight by a lot. On the opposite side, similarly, it is not a single large added mass that is going to increase the overall weight. Therefore also results that seem negligible can provide good overall results. This kind of activity will be the basis for the development of the thesis, with the aim of obtaining a 10% of weight reduction and of having a deeper knowledge about the different interventions that can lead to a weight reduction and their global effects.

2. Area of intervention

To start a weight reduction activity it is necessary to delimitate the area of intervention of the study, to do this some aspects such as car segment and component must be defined before. A first important aspect is the choice of the market segment on which the weight reduction activity can be carried out. Market segmentation is a method to group vehicles from marketing point of view on the basis of some characteristics, for example segment A cars are the smaller and cheaper city car and going on with letters cars become bigger and more luxury.

The most logical choice is to focus the attention on the segment C cars that are the best selling up to now and that from studies it is possible to predict as increasing their presence. (Roland Berger, 2016) It is anyway important to consider that the results obtained during this activity can be generalised and after careful evaluations applied to other car segments.

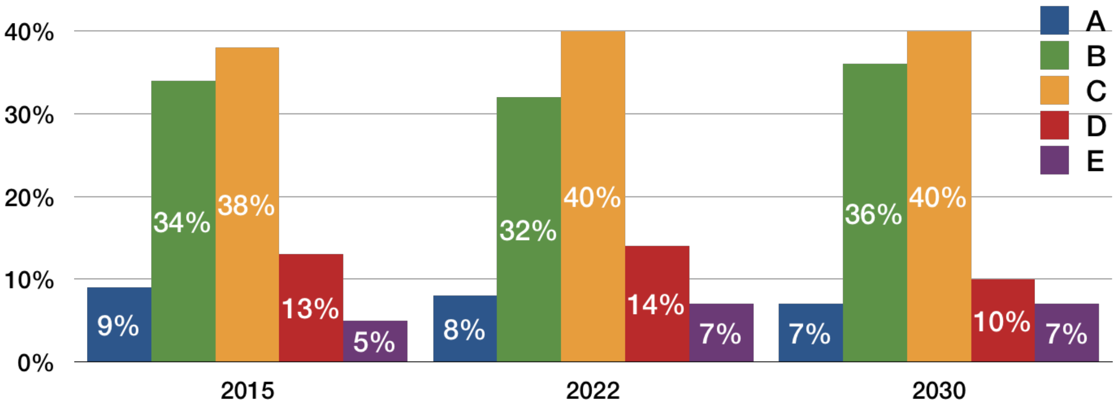

Figure 2.1. Development of new vehicle sales by segment 2014 - 2030

Once that a segment has been chosen, the need to focus on one particular component to start the analysis upraises. Taking into account the overall weight of a car plastic parts represent only the 15% of the total weight that is dominated by the metal part (about 60%), we have to keep in mind that steel density is 7,8 g/cm^3 while general plastic density is 1,2 g/cm^3, moreover considering the last trends the polymers percentage is going to increase in the future thanks to their very interesting properties.

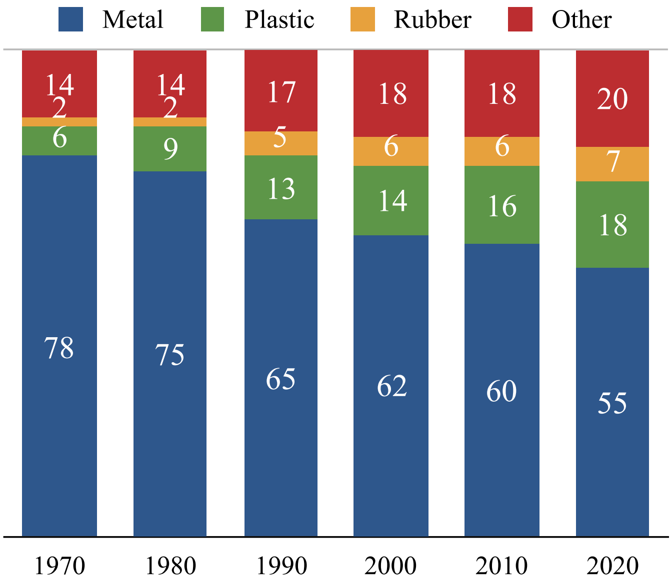

Figure 2.2. Weight percentages of materials used in vehicles over time

Considering the metal components a general trend is the shifting from mild steel grade to high, very high and ultra high strength steel in addition to aluminium alloys and magnesium. Some newer concepts are pointing their attention to the use of plastic composites as metal replacement solution for structural components such as floor pan or B-pillar. (Liraut & Bender, 2015)

This thesis concentrates its effort on plastic components of car interior since they represent more than half of the weight of the different plastic applications in automotive, as it is possible to see form Figure 2.3.

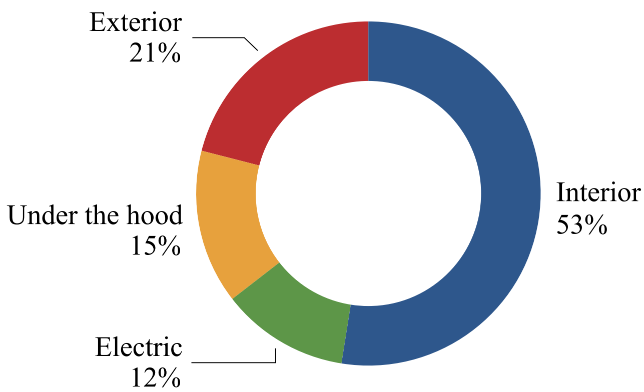

Figure 2.3. Plastics in automotive weights repartition in percentage

Considering therefore automotive interiors plastic component weight repartition it is possible to see from Figure 2.4 that the dashboard takes the main part of the mass (together with trims). The trims are grouping door panels and internal finishing, such as pillar covers, headliner and parcel tray.

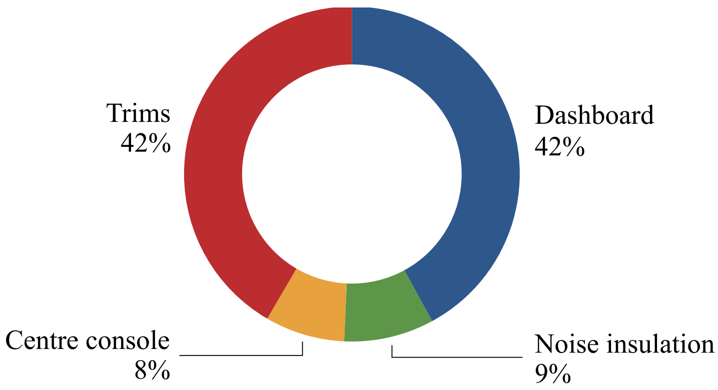

Figure 2.4. Interior weights repartition in percentage

The instrument panel is an important component that is designed to submit different functions in the car, from aesthetic to safety, ergonomic and climatic comfort. In order to meet all these functions it is important to have clear in mind what are the main requirements and tests that a dashboard has to fulfil in order to be validated. In general this requirements goes from environmental (heat, humidity, solar radiation, fluid resistance, etc.) to appearance, physical, mechanical and electrical requirements as well as functional and safety requirement concluding with reliability and durability demands.

Some examples are reported here below:

- Physical requirement: squeak and creaks shall be avoided throughout the whole service temperature interval (from about -30 above 100°C) exploiting the proper materials in the construction of instrument panel assembly.
- Environmental requirement: all components that are within an impact area (i.e. head, knee, airbag, etc.) shall demonstrate ductility at cold temperature overcoming a cold impact test (which consists of a pendulum method that provides a prescribed energy) without exhibiting surface cracks or part breakage.

- Functional requirement: all component surfaces that can be touched by the vehicle occupants shall demonstrate a minimum global surface stiffness in order to transmit to users a sense of rigidity

Generally rigid plastic components are embossed in order to give them an improved tactile sensation since haptic aesthetics is important as visual one. The embossing is a texture that is replicated on the component surface and enables the possibility to decorate it, improve scratch resistance and make objects more functional. In case of moulded object the embossing is realised directly on the mould surface.

Analysing an instrument panel means considering many different components and not a single one. When a group of components and parts, also with different functions, are assembled together is possible to speak of module. This concept has been developed to improve quality, lower costs and better answer all those requirements, Figure 2.5 reports an example of dashboard module in exploded view.

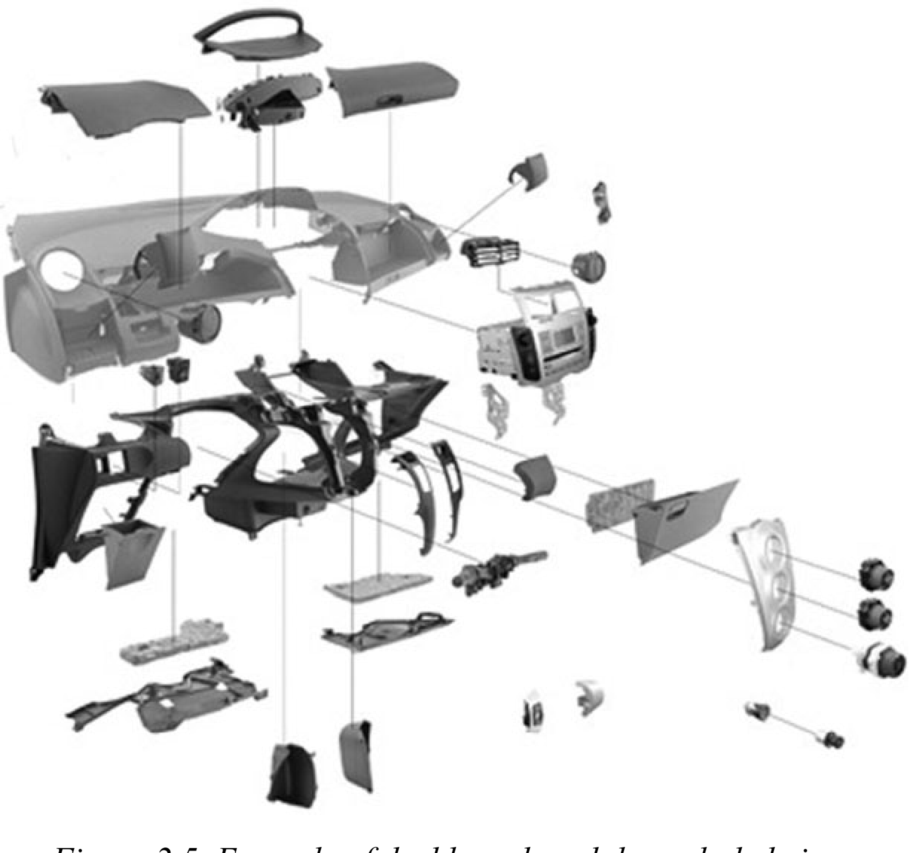

Figure 2.5. Example of dashboard module exploded view

This preliminary part defined the starting point of the study, identifying the instrument panel of a C segment vehicle as the basis to carry out the analysis. The weight reduction will be pursued first looking for different materials that theoretically can ensure the actual performances than exploring different production processes trying to reach better results.

3. Material research

The first part of the thesis points the attention to the different materials employed. The basic material used in car interiors is generally a polypropylene with mineral and elastomeric fillers because it is an economic material with good processability parameters and well-balanced mechanical properties (e.g. resilience and flexural modulus).

Other materials can show worst aesthetic performance, as polypropylene with glass fibres fillers, or can be more expensive, as ABS and polycarbonate blends. Technical components as air vents must be realised in ABS and polycarbonate blends because a polypropylene based material may not be able to guarantee the resistance to impact, especially at low temperatures, while glass fibres reinforced polypropylene can be used for hidden components that require greater strength.

3.1. Strategy

From different OEMs studies various materials can be implemented to obtain weight reduction results considering polypropylene as starting point. It is worth to notice that unfilled polypropylene density is 0,9 g/cm^3 (changing simply the filler type is difficult to reach smaller value of density).

These materials can be mainly categorised by the different type of filler used in the polymer matrix: talc, hollow glass microspheres, natural fibres and nano-fillers, as better described below:

- new talc fillers, this family of polymers is the most common in the automotive industry, the new filler modifies the polymer specific weight from 6% to 8% obtaining similar final performances;
- hollow glass microspheres, filler with very low density (it is the only filler that can lead to a final density smaller than that of the base polymer) that can give all good properties of the glass and thanks to the spheres shows isotropic properties, the weight reduction that can be targeted exploiting this type of material is about 27% with respect to traditional polymers;
- natural fibres fillers, a trend that is consolidating from all OEMs and Tier 1 suppliers is the tendency to exploit natural fibres (hemp, wood, cotton, bamboo, etc.) as filler for polypropylene compounds;

- nano-fillers, generally replacing the glass fibres reinforcement with nano-particles is possible to obtain a density reduction ensuring better stability at different temperatures, better rheological properties and less warpage.

Figure 3.1 shows Scanning Electron Microscopy (SEM) images of the four types of filler in their polymer matrix. In top left figure is possible to see the talc filler, in top right figure are clearly visible the glass microspheres, in bottom left is possible to see the structure of natural fibres in the polymeric matrix and finally in bottom right nano-fillers are highlighted by the circles.

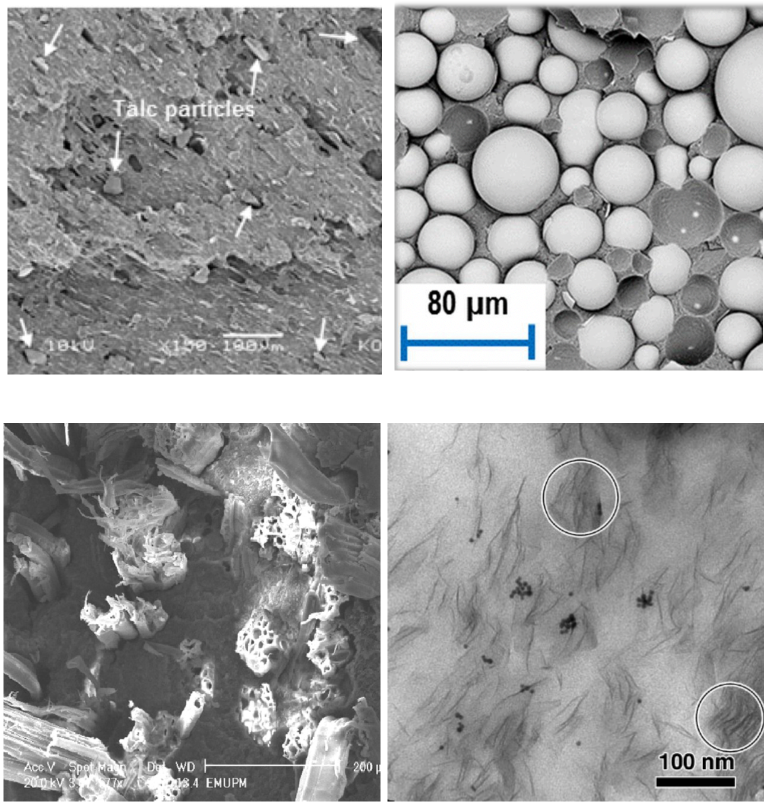

Figure 3.1 Different filler in SEM micrography

Other carmaker are working to obtain weight reduction exploiting the materials, an example is the new C segment vehicle by a Czech carmaker where a weight reduction of 6,5% on the lower dashboard part, glove box and centre console has been obtained exploiting an elastomer modified polypropylene with 10% of talc filler. (Borealis AG, 2019)

An other example is the substitution of traditional glass fibre reinforced material with natural fibre ones with a density reduction ranging from 15% to 25%, this is the approach of a French Tier 1 supplier on Italian and French C and D segment cars, instrument panel carrier. (Faurecia, 2017)

A material with hollow glass microsphere and glass fibres reinforcement has been used instead for the covered dashboard of an important Italian D segment SUV obtaining a weight reduction of 28% with respect to the traditional material. (Servetti, 2017)

A Tier 1 supplier on German car electric model exploits natural fibres (kenaf) on aesthetical components, door panels and dashboard cover, on specific carmaker requirement but it is worth to notice that the production technology exploited is a cold pressing and not injection moulding. (Schmiedel, Barfuss, Nickel, & Pfeufer, 2014)

The starting point of the analysis is the state of the art of a C segment car dashboard, as defined in the first part, taking into account the different materials employed in the actual production. Table 3.1 is the basis of the analysis and it has been built in order to simplify the study and to permit the comparison the different materials and their theoretical performances, taking into account some important parameters on the base given by the validation requirements.

Component identification							
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**	**Design mass**	**Delta mass**

Table 3.1. Material comparison basis

Component and material identification are reported first, for what concern material identification the name is not enough and a second column reports some indications about fillers and other specific properties. It is important to underline the fact that materials research was carried out starting from the materials currently available on the market, therefore the data were searched on material producers websites and also by meetings with the representatives of the companies.

It is clear that to obtain a result in weight reduction the parameter that must be taken into account is the density of the polymer, therefore this factor has been used as discriminant to decide if a material has to be listed in the table or not.

As it has been described before the dashboard must satisfy specific validation requirements to meet its mission profile, so also technological properties have been accounted for, in particular some peculiar of them have been identified in the melt flow index, flexural modulus of elasticity and IZOD resilience.

The list below explains the different technology parameters:

- **Melt Flow Index (MFI) or Melt Flow Rate (MFR)**
  It is a measure of how easy a polymer can flow through a capillary and it is expressed in units of grams per 10 minutes. The ISO standard 1133-1:2011 defines it as:
  "Rate of extrusion of a molten resin through a die of specified length and diameter under prescribed conditions of temperature, load and piston position in the cylinder of an extrusion plastometer, the rate being determined as the mass extruded over a specified time."
  The greater the mass of flown material, the greater the Melt Flow Index and the lower the viscosity of the polymer. In injection moulding is preferable to exploit polymers with lower viscosity that means higher MFI;

- **Flexural modulus of elasticity**
  It is a property expressed in N/mm^2 that is computed as the ratio of stress to strain in flexural deformation and can be interpreted as the tendency for a material to resist to bending. The ISO standard 178:2001 defines it as:
  "The test specimen, supported as a beam, is deflected at a constant rate at the midspan until the specimen fractures or until the deformation reaches some predetermined value. During this procedure, the force applied to the test specimen is measured";

- **IZOD resilience**
  It is a measure of material ability to absorb energy during plastic deformation. The ISO standard 180:2000 define the IZOD impact strength as:
  "The method is used to investigate the behaviour of specified types of specimen under the impact conditions defined and for estimating the brittleness or toughness of specimens within the limitations inherent in the test conditions. [...] Impact energy absorbed in breaking a notched specimen, referred to the original cross-sectional area of the specimen at the notch, with the pendulum striking the face containing the notch. It is expressed in kilojoules per square metre (kJ/m^2)".
  Brittle materials have low toughness, thus low IZOD resilience, as a result of the small amount of plastic deformation they can tolerate. The IZOD

resilience of a material can also change with temperature; generally at lower temperatures the impact energy of a material is decreased.

Nevertheless these parameters are not enough to have the assurance that the same component, with the same actual design, will be able to satisfy the requirements for component validation considering a material change only. Indeed they are intended as general indexes that can quantify some intrinsic properties of the material, which give back a general idea of its behaviour with respect to the reference material.

This first analysis is concluded evaluating the theoretical variation of mass, setting the starting point as the mass of the component as in design stage. The production mass would lead to biased results since a fine-tuning of the production process parameters can have been done, for example packing more the material would lead to heavier components.

A second analysis can be carried out considering other significant properties. A particular position is occupied by the aesthetic requirements since components that are in sight are crucial for the subjective vehicle evaluation by the customers. Nowadays OEMs are looking for low gloss and scratch resistant materials to improve the customer perceived quality.

Cost have not been considered as a discriminant parameter during the development of the comparative table, Table 3.1, because the scope of the thesis is to highlight some possible light weighting solutions and their effectiveness rather than the economical feasibility.

3.2. Components analysis

Considering the dashboard module it is possible to see that the main part of the weight is taken by the dashboard and correspond to 8 kg, considering than the glove box other 2 kg are taken into account getting to an overall 60% of plastic components of instrument panel assembly, the remaining 40% can be split between instrumentation, and other trims. The percentages repartition of dashboard module plastic components can be seen in Figure 3.2.

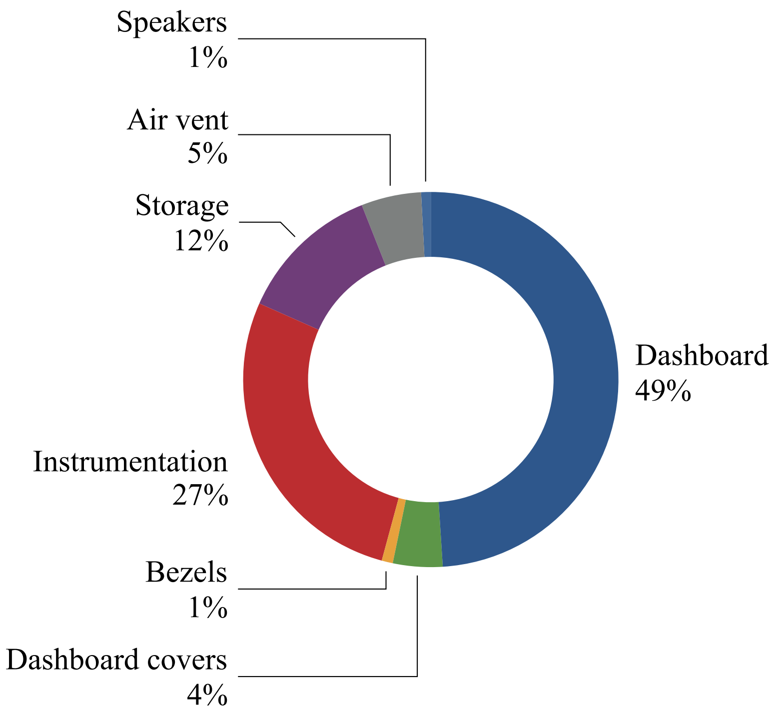

Figure 3.2. Dashboard plastic components weights repartition in percentage

A first distinction must be done: a vehicle can be generally equipped with a stiff instrument panel more economic but with limited aesthetic feelings (although improved exploiting the embossing), or with a foamed instrument panel that improves the aesthetic perception and customer's perceived quality to the detriment of the economic aspects.

These two configurations carry out a similar but different decomposition of the instrument panel module with some common components and other that are different, as it is possible to see from Figure 3.3 and Figure 3.4. The top cover is assembled by means of ultrasonic welding on the dashboard body that hosts also three reinforcements and the glove box assembly. The object of the analysis presents both versions, stiff and foamed, in particular the top cover is realised in two versions that differentiate the stiff and the foamed configuration. The stiff version requires some spacers that set the corrects flushes and gaps between top cover and dashboard body because the top cover of the foamed version is thicker since it is decomposed in an insert, a foam and a cover.

Figure 3.3 and Figure 3.4 report an exploded view of the dashboard module main components respectively in the stiff and foamed variations. It is possible to see the stiff top cover, dashboard body, air vents, glove box and some trims, the dashboard body shown is comprehensive of its own reinforcements and defroster duct.

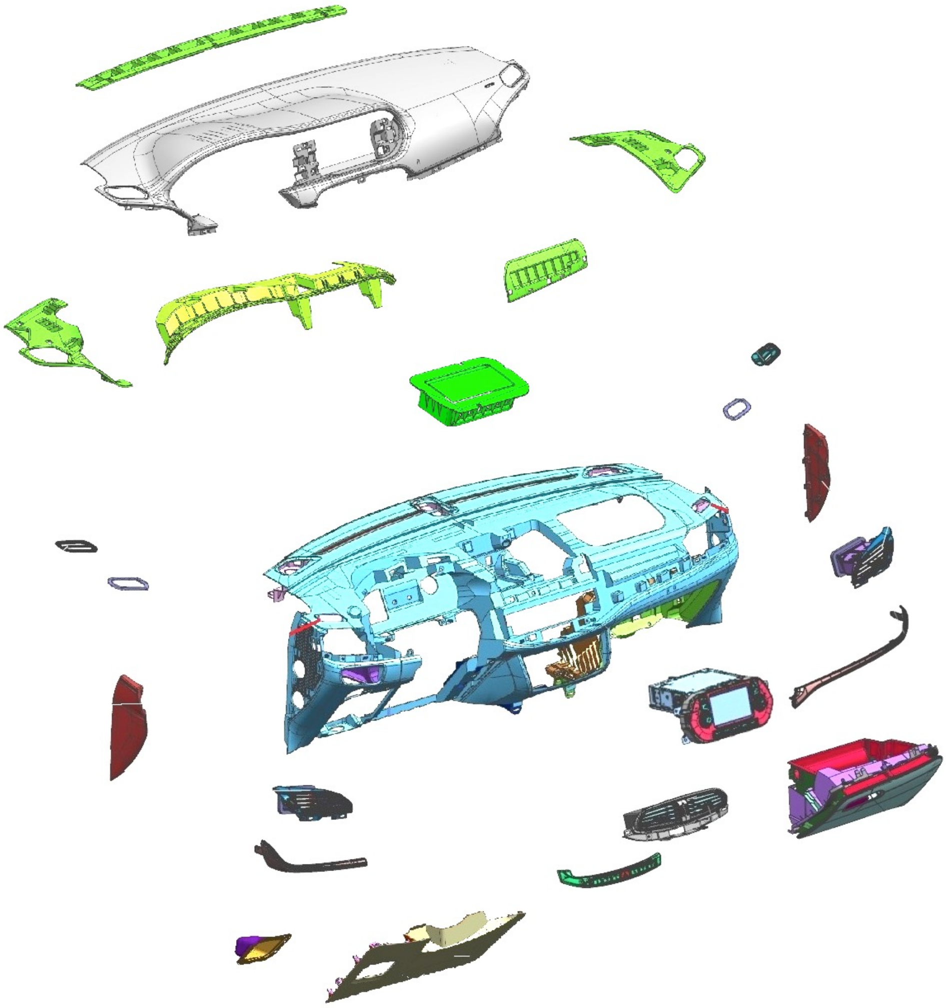

Figure 3.3. Main plastic components of the stiff dashboard

Figure 3.4. Main plastic components of the foamed dashboard

The correct coupling between components must be guaranteed because carmakers write a document that declares all the flushes and gaps that must be respected in significant sections of a specific assembly. Therefore components dimensions have to be the most stable possible.

There are different methods to couple dashboard components, from mechanical fasteners to snap fits design, but one of the main joining technology for plastic components is welding. To ensure that this process works correctly the parts to be welded must be realised with the same thermoplastic material and only filler variation can be accepted, after careful evaluations. This is because the joining of the components requires the plastic local melting so that the joint interface can mix and form a stable connection after cooling.

Table 3.2 reports a small overview about the compatibility of the main materials employed in automotive industry. Ultrasonic welding is one of the most widespread technologies for thermoplastic joining. This process is based on high frequency ultrasonic energy that is exploited to generate mechanical vibrations with small amplitude as heat generator at joint interface.

Material Family	ABS	Elastomers TPE/TPO	PA	PC	PC/ABS	PP	PVC
ABS	●	○		○	●		○
Elastomers TPE/TPO	○	●				●	
PA			●			○	
PC	○			●	●	○	○
PC/ABS	●			●	●		○
PP		●	○	○		●	
PVC	○			○	○		●

● Compatible
○ Somewhat compatible
Generally not compatible

Table 3.2. Compatibility of thermoplastic materials welding

3.2.1. Dashboard body

The dashboard body is the main element of the module because of its great dimensions, as can be appreciated in Figure 3.5, it is moulded in polypropylene with 10% of talc filler and it has some surfaces that are visible, therefore the aesthetic finishing (embossing) is required. Onto the dashboard body many different components are going to be fixed both through snaps and welding technology.

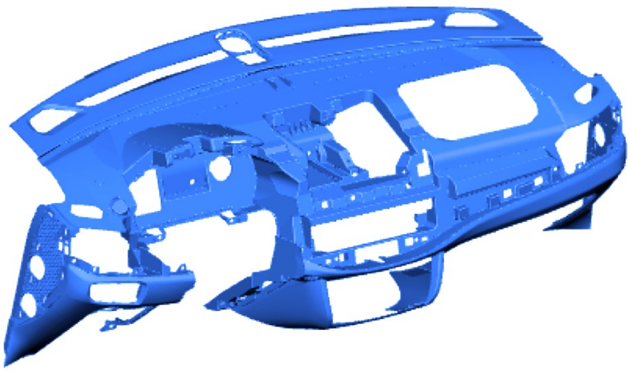

Figure 3.5. Dashboard body

Dashboard body										
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**		**Design mass**	**Delta mass**		**Note**
-	**-**	**g/cm^3**	**g/10min**	**23°C [N/mm^2]**	**23°C [kJ/m^2]**	**−30°C [kJ/m^2]**	**g**	**g**	**%**	
Reference material	*Copolimer 10% mineral filler Scratch resistant*	*0,97 ÷ 1*	*8 ÷ 12*	*>1650*	*>18*	*>4*	2890	-	-	*Material used to produce the component*
Mat.1	PP elastomer modified	0,905	22	1000	38	6	2669	-221	**-8%**	Low mechanical performances
Mat.2	PP	0,905	14	1450	*Not available*	*Not available*	2669	-221	**-8%**	Low mechanical performances
Mat.3	PP 10% mineral filler, scratch resistant	0,97	20	1800	*Not available*	*Not available*	2861	-29	**-1%**	No weight reduction
Mat.4	PP 5% talc	0,93	16	1650	28	5	2743	-147	**-5%**	Material that can satisfy the considered properties
Mat.5	PP talc filler	0,96	19	2600	4,5	2,6	2831	-59	**-2%**	IZOD not sufficient
Mat.6	PP 12% talc	0,98	23	1750	40	5	2890	0	**-0%**	No weight reduction
Mat.7	PP microcomposite	0,92	22	1850	3,5	1,5	2713	-177	**-7%**	IZOD not sufficient
Mat.8	PP microcomposite	0,98	20	2500	3.7	1,6	2890	0	**-0%**	No weight reduction

Table 3.3. Dashboard body materials comparison

In the first row of the Table 3.3 is reported the Reference material, i.e. the material employed right now for the production of the dashboard body. It is a polypropylene with 10% of mineral filler characterised by a flexural modulus of elasticity of 1650 N/mm^2, IZOD resiliencies of 18 kJ/m^2 at 23°C and of 4 kJ/m^2 at -30°C. The starting density of 0,98 g/cm^3 is already a good value if compared to the founded materials. The component moulded with this material weighs 2890 g. The other rows report different materials (always polypropylene based) that show a lower density. The Mat.4 that is characterised by a 5% of talc filler may be able to satisfy the properties taken into account obtaining at the same time a weight reduction (-147 g, -5%). On the other hand some materials as Mat.1 or Mat.2 show an interesting result regarding the weight reduction (up to -8% that means more than 200 g) but the drawbacks are the mechanical properties that do not ensure the same performances of the reference material.

Since a material has been identified, it is possible to perform a second analysis, here it is possible to verify the presence of other properties such as gloss and scratch resistance, as reported on the technical data sheet supplied by the suppliers. Table 3.4 reports a comparison between Reference material and Mat.4 about these properties: the only parameter missing for Mat.4 is the good dimensional stability, while both have low gloss and scratch resistance. Hence there is the possibility that the component does not preserve its original configuration correctly while experiencing environmental changes.

Name	Good dimensional stability	Low gloss	Scratch resistant
Reference material	●	●	●
Mat.4		●	●

Table 3.4. Dashboard body material second analysis

This type of material seems a promising alternative to current one although the poor result in weight reduction. As a matter of fact it has been already used for door panel and other trims by a German carmaker but it has not been applied to dashboard body yet.

As already mentioned, other companies are working also with natural fibres and hollow glass microspheres and glass fibre reinforced materials. These kinds of materials have not been considered for this component because: in case of natural fibre reinforced plastic is intended for covered or non-visible applications because of the low aesthetic performances, while for hollow glass microspheres material aesthetical defects as flow lines can appear, some trials had been performed by Martur Fompak International R&D department before the start of this thesis on both dashboard body and top cover.

This is the reason why it will not be considered for those components that result to be aesthetical such as the dashboard body just analysed and the stiff top cover reported in the next section.

3.2.2. Stiff top cover

The stiff top cover, represented in Figure 3.6, is a very important component of the rigid dashboard assembly because it is going to be installed on the upper part of the dashboard body. Given its position in the passenger compartment, it must be thrown to meet the tactile requirements and, being contactable in the event of an accident, it must be made of ductile material, in addition it must integrate the passenger airbag shoot channel. The analysed model integrates demister exits that will hosts their own bezels on the sides, additionally the fixing points of the infotainment can be individuated in the central area.

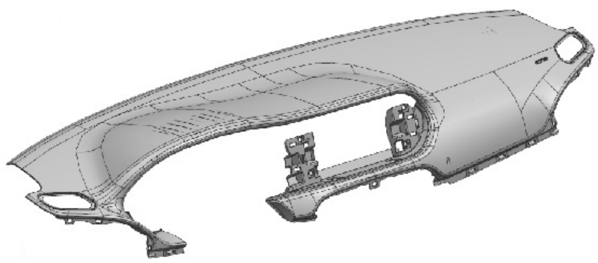

Figure 3.6. Stiff top cover

On the stiff top cover are welded also other components. In Figure 3.7 is possible to see the stiff top cover as it comes out from the welding machine. First the upper rigid cover is placed on the holding fixture in the upside down position, so the spacers, the instrument cover reinforcement and the airbag shoot channel are placed in the correct position by the operator. At this stage ultrasonic welding is employed to fix the different components.

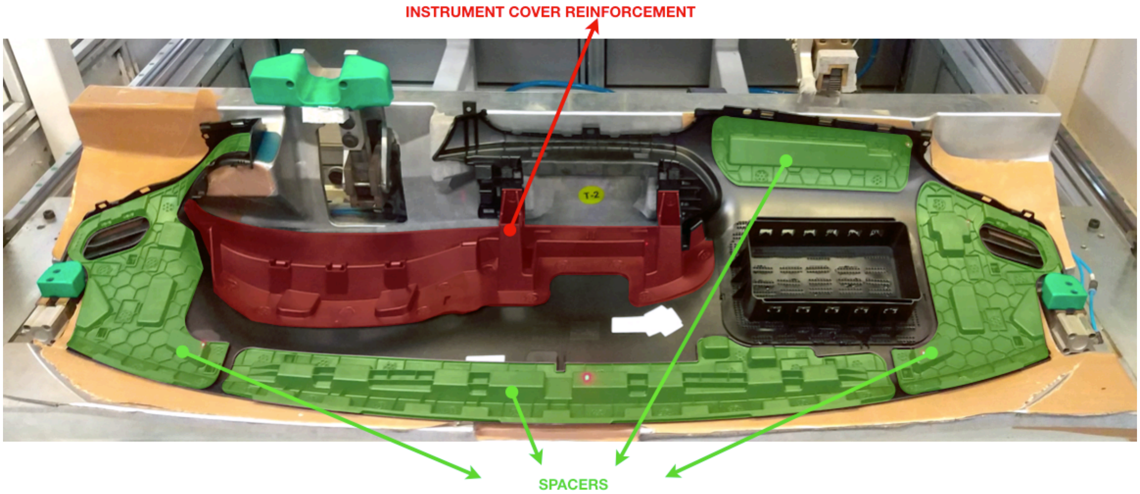

Figure 3.7. Stiff top cover after welding

Stiff upper cover										
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**		**Design mass**	**Delta mass**		**Note**
-	**-**	**g/cm³**	**g/10min**	**23°C [N/mm²]**	**23°C [kJ/m²]**	**–30°C [kJ/m²]**	**g**	**g**	**%**	
Reference material	*Copolimer Min. filler (talc) 20% High fluidity Impact resistant*	*1,02 ÷ 1,05*	*19 ÷ 25*	*>1700*	*>45*	*>6*	1744	-	-	*Material used to produce the component*
Mat.1	PP elastomer modified	0,905	22	1000	38	6	1532	-212	**-14%**	Low mechanical performances
Mat.2	PP	0,905	14	1450	*Not available*	*Not available*	1532	-212	**-14%**	Low mechanical performances
Mat.3	PP 10% mineral filler, scratch resistant	0,97	20	1800	*Not available*	*Not available*	1642	-102	**-6%**	Material that can satisfy the considered properties
Mat.4	PP 5% talc	0,93	16	1650	28	5	1575	-169	**-11%**	IZOD not sufficient
Mat.5	PP talc filler	0,96	19	2600	4,5	2,6	1625	-119	**-7%**	IZOD not sufficient
Mat.6	PP 12% talc	0,98	23	1750	40	5	1659	-85	**-5%**	Material that can satisfy the considered properties
Mat.7	PP microcomposite	0,92	22	1850	3,5	1,5	1558	-186	**-12%**	IZOD not sufficient
Mat.8	PP microcomposite	0,98	20	2500	3.7	1,6	1659	-85	**-5%**	IZOD not sufficient

Table 3.5. Stiff top cover materials comparison

The Reference material, reported in the first row of Table 3.5, is a polypropylene with 20% of talc filler and a density of 1,03 g/cm^3. It is the material employed right now for the injection moulding of the component that weighs 1744 grams. It is characterised by an IZOD resilience of 45 kJ/m^2 at ambient temperature and of 6 kJ/m^2 at -30°C, high value when compared to the found materials with lower density reported into the other rows.

Between these materials Mat.6, which is characterised by a 12% of talc filler, may satisfy the parameters taken into account obtaining at the same time a weight reduction (-85 g, -5%). A particular attention to IZOD resiliencies have to be paid since Mat.6 values are close but not greater than the Reference material ones.

On the other hand some materials as Mat.1 and Mat.2 show an interesting result regarding the weight reduction (up to -212 g, -14 %) but the drawbacks are the mechanical parameters that do not ensure the performances of the Reference material. Analysed materials with micro-composite filler despite the very good flexural modulus of elasticity show too low IZOD resiliencies, for this reason they cannot be employed in this application.

Once that a material has been identified from the first analysis, it is possible to check for other properties as colourability, impact resistance and gloss, performing a further analysis. Table 3.6 reports this second analysis performed for the stiff top cover and shows that there can be problem about impact resistance and colourability.

Name	Good colourability	Good flow	Good mouldability	High impact resistance	High stiffness	Low gloss	Scratch resistant
Reference material	●	●	●	●	●	●	●
Mat.6		●	●			●	●

Table 3.6. Stiff top cover material second analysis

As already seen in the first analysis, the stiffness and impact resistance are the properties that lays close to the ones of actual material, therefore a particular attention must be used when considering Mat.6 application. This material has been recently introduced in OEM standards for dashboards, dashboard components and door panels applications; unfortunately the expected weight reduction result is 5% which is lower than the 10% target.

3.2.3. Instrument cover reinforcement

The instrument cover reinforcement, which CAD model is represented in Figure 3.8, is a component that gives the correct rigidity to the cluster area and in this configuration hosts also the fixing points for the infotainment module. It is welded to the dashboard top cover as shown in Figure 3.7.

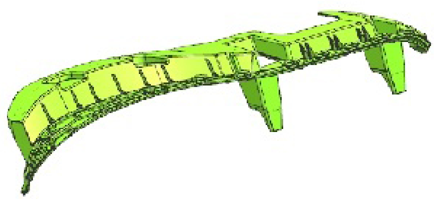

Figure 3.8. Instrument cover reinforcement

Instrument cover reinforcement										
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**		**Design mass**	**Delta mass**		**Note**
-	-	**g/cm^3**	**g/10min**	**23°C [N/mm^2]**	**23°C [kJ/m^2]**	**–30°C [kJ/m^2]**	**g**	**g**	**%**	
Reference material	*Copolimer mineral filler (25% talc)*	*1,05 ÷ 1,12*	*3 ÷ 8*	*>1900*	*>10*	*>3*	430	-	-	*Material used to produce the component*
Mat.1	PP elastomer modified	0,905	22	1000	38	6	364	-66	**-18%**	Low mechanical performances
Mat.2	PP	0,905	14	1450	*Not available*	*Not available*	364	-66	**-18%**	Low mechanical performances
Mat.3	PP 10% mineral filler, scratch resistant	0,97	20	1800	*Not available*	*Not available*	390	-40	**-10%**	Low mechanical performances
Mat.4	PP 5% talc	0,93	16	1650	28	5	374	-56	**-15%**	Low mechanical performances
Mat.5	PP talc filler	0,96	19	2600	4,5	2,6	386	-44	**-11%**	IZOD not sufficient
Mat.6	PP 12% talc	0,98	23	1750	40	5	394	-36	**-9%**	Low mechanical performances
Mat.7	PP microcomposite	0,92	22	1850	3,5	1,5	370	-60	**-16%**	IZOD not sufficient
Mat.8	PP microcomposite	0,98	20	2500	3.7	1,6	394	-36	**-9%**	IZOD not sufficient

Table 3.7. Instrument cover reinforcement materials comparison

As it is possible to see from the comparison table, Table 3.7, the material actually employed in production is a polypropylene with mineral filler (25% talc) that has a density of 1,07 g/cm^3 and characterised by flexural modulus of elasticity of 1900 MPa. The moulded instrument cover reinforcement weighs 430 grams when Reference material is employed.

Materials (always polypropylene based) with lower density are reported in the other rows of Table 3.7, the research highlights that no one of the analysed materials with lower density can ensure the mechanical properties guaranteed by the actual one.

As an example the materials that where acceptable for dashboard body Mat.6, with 12% of talc filler, or stiff top cover Mat.3, that has 10% of mineral filler, present a lower flexural modulus of elasticity (respectively 1750 MPa and 1800 MPa) with respect to Reference material that is 1900 MPa. On the contrary Mat.5 that displays a greater flexural modulus of elasticity (2600 MPa) is not satisfying the IZOD performances with 4,5 kJ/m^2 with respect to the 10 kJ/m^2 of the Reference material, in particular at ambient temperature.

Materials with micro-composite fillers also show excessively low IZOD performances with 3,5 kJ/m^2 and 3,7 kJ/m^2 if Mat.7 or Mat.8 are considered; although flexural modulus of elasticity is close to the Reference material one and the theoretical weight reduction result is one of the best, up to 16% less in case of Mat.6 that would mean a final mass of 370 grams.

3.2.4. Spacers, defroster duct, dashboard reinforcements

Spacers, defroster duct and dashboard reinforcements are going to be presented together because they are realised exploiting the same material, in particular a polypropylene with 20% talc filler as can be seen from Table 3.8. These components are not on user sights so no aesthetical requirement is applied to them.

The four spacers represented in

Figure 3.9 are assembled only on rigid version of the dashboard assembly and are designed to ensure the correct alignment of stiff top cover shape with respect to dashboard body profile. These four components, which together accounts for 580 grams, are fixed to the dashboard stiff top cover by means of ultrasonic welding as shown in Figure 3.7.

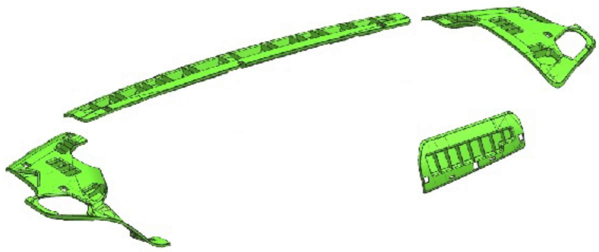

Figure 3.9. Spacers for top cover

The defroster duct has the task of carrying the air coming from the central HVAC (Heating Ventilation Air Conditioning) system to the defroster and demister outlet. While the defroster is placed right under the windshield, demister outlets are on the sides of the dashboard, as described in Figure 3.6 directing the air towards the front side glasses. This is an important preventive safety device since minimum requirements about demisting and defrosting performances must be respected in order to guarantee the correct level of visibility. In order to realise the duct an omega shape is moulded and than welded to dashboard body, thanks to its boxed shape the defroster duct stiffen also the dashboard in the windshield region.

Figure 3.10. Defroster duct

Finally dashboard reinforcements are welded to the lower part of the dashboard body, these must guarantee the correct stiffness of this area since it is crucial in crash performances considering the knee impact. The third reinforcement hosts also the glove box assembly so it has to guarantee the correct functioning of this component too.

The three components together accounts for 1027 grams while the duct weighs described before 912 grams.

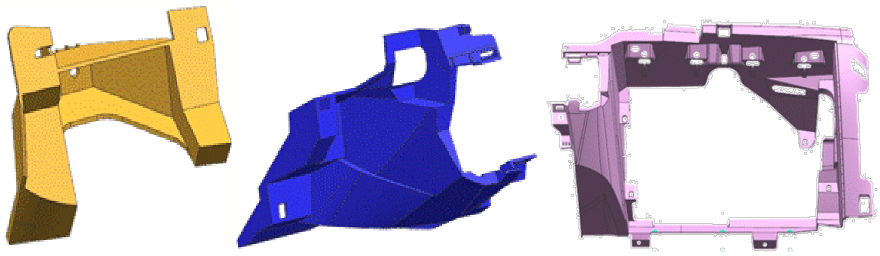

Figure 3.11. Dashboard reinforcements

Spacers, Defroster duct, Dashboard reinforcements										
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**		**Design mass**	**Delta mass**		**Note**
-	-	**g/cm^3**	**g/10min**	**23°C [N/mm^2]**	**23°C [kJ/m^2]**	**–30°C [kJ/m^2]**	**g**	**g**	**%**	
Reference material	*Copolimer talc filler 25%*	*1,03 ÷ 1,08*	*7 ÷ 12*	*>2100*	*>2*	-	2519	-	-	*Material used to produce the component*
Mat.1	PP elastomer modified	0,905	22	1000	38	6	2260	-259	**-11%**	Low mechanical performances
Mat.6	PP 12% talc	0,98	23	1750	40	5	2351	-168	**-7%**	Low mechanical performances
Mat.7	PP microcomposite	0,92	22	1850	3,5	1,5	2207	-312	**-14%**	Low mechanical performances
Mat.8	PP microcomposite	0,98	20	2500	3.7	1,6	2351	-168	**-7%**	Low mechanical performances
Mat.9	PP biocomposite 30% wood fibres	1	17	2950	4,2	*Not available*	2399	-120	**-5%**	Can show odour problem
Mat.10	PP reinforced 20% hemp fibre	0,98	22	*Not available*	7,5	*Not available*	2351	-168	**-7%**	Can show odour problem
Mat.11	PP GF GB	0,83	8	3050	6	*Not available*	1991	-528	**-27%**	Can show welding problem
Mat.12	PP 20%GF 10%GB	0,95	*Not available*	4200	8	*Not available*	2279	-240	**-11%**	Can show welding problem
Mat.13	PP 10%GF 20%GB	0,83	*Not available*	3200	6,5	*Not available*	1991	-528	**-27%**	Can show welding problem

Table 3.8. Spacers, defroster duct and dashboard reinforcements materials comparison

As shown in Table 3.8 the Reference material, the polypropylene with 25% of talc filler reported in the first row, has a density of 1,05 g/cm^3 and it is characterised by a very low IZOD resilience but good flexural elastic modulus if compared to other analysed materials. The four components as a whole weigh 2519 grams. Subsequent rows show that also materials with natural fillers rather than hollow glass microspheres have been taken into account for these components.

In case of materials with micro-composite fillers as Mat.7 or Mat.8 the theoretical weight reduction result is up to 14% that would produce a final mass of 312 grams. IZOD performances (3,5 and 3,7 kJ/m^2 respectively) are close to the required one, >2 kJ/m^2 but unfortunately the flexural modulus of elasticity is too low with respect to the Reference material one that means that these materials are not adequate too.

While in case of natural fibres reinforced materials the problem emerged is the possibility that odour can be emitted after the moulding, materials with hollow glass microspheres contain also glass fibre because they have to guarantee a level of mechanical performances. The glass present in this material can create welding problems if the sonotrodes are not treated as revealed by some test performed in Martur Fompak's laboratories.

3.2.5. Glove box and Fuses cover

For completeness of the study it is now analysed the glove box assembly that is constituted by three main components: drawer, cover and reinforcement. It is placed in the lower part of dashboard on passenger side and its validation requirements are mainly based on load application and maximum admitted deflection on specific zones.

The fuses cover completes the lower part of the dashboard on driver side and taking into consideration all the components mentioned above, is obtained a total weight of 1936 grams.

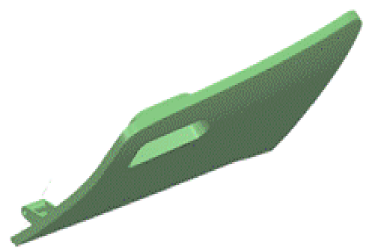

Figure 3.12. Glove box cover

The material employed in the manufacturing process of the glove box cover, represented in Figure 3.12, is the same polypropylene employed for the instrument cover reinforcement production: characterised by 25% talc filler that has a density of 1,07 g/cm^3, 1900 MPa as flexural modulus of elasticity and IZOD resiliencies of 10 kJ/m^2 and 3 kJ/m^2 at ambient temperature and -30°C respectively. This cover alone weighs 420 grams considering the actual material.

The result of the research already performed for the instrument cover reinforcement are the one shown in Table 3.7 and they highlight that no one of the considered materials with lower density can ensure the mechanical properties ensured by the actual one.

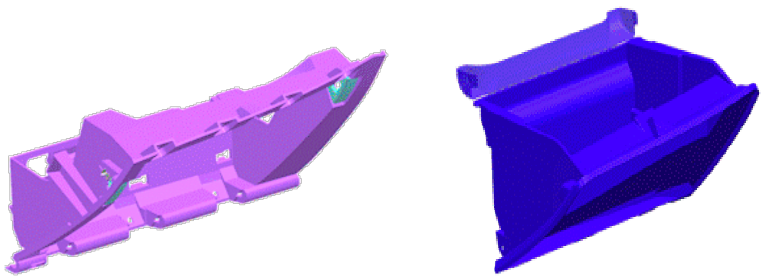

Figure 3.13. Glove box reinforcement (left) and glove box drawer (right)

The glove box drawer and reinforcement, despite they might seem non-aesthetical components, come in sight when the glove box is open. They host the hinges and the opening mechanisms with the handle that is operated by the occupants. These components are moulded with a material that has a density of 1,12 g/cm^3 and they weigh together 1227 grams.

As show in Table 3.9 it has been not possible to find a material that would lower the weight maintaining unaltered the performances assured by the Reference one. The material that would ensure the minimum flexural modulus, as Mat.5, would not ensure the sufficient IZOD resilience.

Glove box drawer and reinforcement										
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**		**Design mass**	**Delta mass**		**Note**
-	**-**	**g/cm^3**	**g/10min**	**23°C [N/mm^2]**	**23°C [kJ/m^2]**	**–30°C [kJ/m^2]**	**g**	**g**	**%**	
Reference material	*Mineral (talc) filled copolymer 25%*	*1,11 ÷ 1,17*	*4 ÷ 10*	*>2500*	*>7*	*>2,5*	1227	-	-	*Material used to produce the component*
Mat.1	PP elastomer modified	0,905	22	1000	38	6	991	-236	**-24%**	Low mechanical performances
Mat.2	PP	0,905	14	1450	*Not available*	*Not available*	991	-236	**-24%**	Low mechanical performances
Mat.3	PP 10% mineral filler, scratch resistant	0,97	20	1800	*Not available*	*Not available*	1063	-164	**-15%**	Low mechanical performances
Mat.4	PP 5% talc	0,93	16	1650	28	5	1019	-208	**-20%**	Low mechanical performances
Mat.5	PP talc filler	0,96	19	2600	4,5	2,6	1052	-175	**-17%**	IZOD not sufficient
Mat.6	PP 12% talc	0,98	23	1750	40	5	1074	-153	**-14%**	Low mechanical performances
Mat.7	PP microcomposite	0,92	22	1850	3,5	1,5	1008	-219	**-22%**	IZOD not sufficient
Mat.8	PP microcomposite	0,98	20	2500	3.7	1,6	1074	-153	**-14%**	IZOD not sufficient

Table 3.9. Glove box drawer and reinforcement materials comparison

In the lower part of the dashboard on driver side, under the steering column cover, is possible to find also the fuses cover, this cover is intended for maintenance so it has to be removable and has a final weight of 289 grams.

It is manufactured utilising the same polypropylene material employed for dashboard body production described in Table 3.3 and Table 3.4, which has 10% of mineral filler and is characterised by a flexural modulus of elasticity of 1650 N/mm^2, IZOD resiliencies of 18 kJ/m^2 at 23°C and of 4 kJ/m^2 at -30°C.

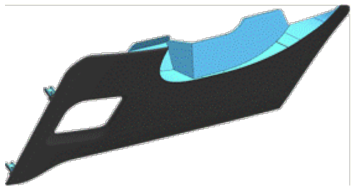

Figure 3.14. Fuses cover

Since the material used for fuses cover production is the same of dashboard body, the founded material able to satisfy the properties taken into account, obtaining at the same time a weight reduction, is Mat.4 highlighted in Table 3.3 and characterised by a 5% of talc filler. Theoretically if it would be employed for the fuses cover production would lead to a weight reduction of 15 grams equivalent to a 5% of weight saved and a total mass of 274 grams.

3.2.6. Foamed top cover

Once analysed the rigid version of the dashboard is possible to consider the foamed one. In this case the top cover can be decomposed into three parts: the cover, the foam and the foam support (or insert). While the first is generally a vacuum-thermoformed TPO sheet and the foam is usually polyurethane, the focus can be pointed mainly on the last component, the insert, which can be simpler since no aesthetic requirement is applied to it. Moreover, while in the rigid version of the dashboard the impact performances have to be guaranteed by the stiff top cover only, instead in the soft version the whole assembly have to guarantee them.

Figure 3.15 represents the CAD model of the insert of the foamed top cover, it is possible to see an hole on passenger side that is intended to hosts the airbag shoot channel, which is fitted and glued to the insert. This different installation method with respect to the stiff top cover of the airbag shoot channel, together with the fact that the component does not results to be on customer sight, allows to take into consideration also materials such as polypropylene with hollow glass microspheres filler or natural fibres filler.

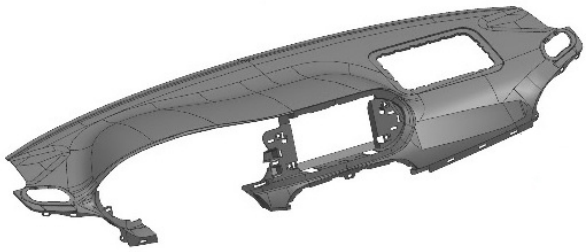

Figure 3.15. Insert for foamed top cover

Insert for foamed top cover										
Name	**Properties**	**Density**	**MFI**	**Flexural modulus of elasticity**	**IZOD notched resilience**		**Design mass**	**Delta mass**		**Note**
-	-	**g/cm^3**	**g/10min**	**23°C [N/mm^2]**	**23°C [kJ/m^2]**	**–30°C [kJ/m^2]**	**g**	**g**	**%**	
Reference material	*Copolimer Min. filler (talc) 20% High fluidity Impact resistant*	*1,02 ÷ 1,05*	*19 ÷ 25*	*>1700*	*>45*	*>6*	2161	-	-	*Material used to produce the component*
Mat.1	PP elastomer modified	0,905	22	1000	38	6	2014	-147	**-7%**	Low mechanical performances
Mat.6	PP 12% talc	0,98	23	1750	40	5	2056	-105	**-5%**	Low mechanical performances
Mat.7	PP microcomposite	0,92	22	1850	3,5	1,5	1930	-231	**-12%**	Low IZOD performances
Mat.8	PP microcomposite	0,98	20	2500	3.7	1,6	2056	-105	**-5%**	Low mechanical performances
Mat.9	PP biocomposite 30% wood fibres	1	17	2950	4,2	-	2098	-63	**-3%**	Can show odour problem
Mat.10	PP reinforced 20% hemp fibre	0,98	22	*Not available*	7.5	-	2056	-103	**-5%**	Can show odour problem
Mat.11	PP GF GB	0,83	8	3050	6	-	1741	-420	**-24%**	Can show welding problem
Mat.12	PP 20%GF 10%GB	0,95	*Not available*	4200	8	-	1993	-168	**-8%**	Can show welding problem
Mat.13	PP 10%GF 20%GB	0,83	*Not available*	3200	6,5	-	1741	-420	**-24%**	Can show welding problem

Table 3.10. Insert for foamed top cover materials comparison

The component weight is 2161 grams. The Reference material reported in first row of Table 3.10 is a polypropylene with 20% of talc filler and is the same employed for the injection moulding of the stiff top cover with a density of 1,03 g/cm^3.

In the following rows is possible to find different materials that have a lower density: as an example Mat.6 is the material individuated during the research for the stiff top cover material, it would lead to a weight reduction of 105 grams, corresponding to a 5% reduction.

Shifting the attention to materials with natural fibres reinforcement is possible to see that the weight reduction is really marginal and may not satisfy the impact requirements. Instead hollow glass microspheres filler, as already explained in spacers, defroster duct and dashboard reinforcements analysis, can show welding problems.

3.3. CONSIDERATIONS ON MATERIAL RESEARCH

In this chapter different components of the dashboard module have been analysed from the point of view of materials, searching for the existence of alternatives that could lead to a reduction in weight without compromising some characteristics considered as priorities, such as IZOD resilience or the flexural modulus of elasticity. These characteristics are not sufficient to guarantee that the replacement of the material in use meets the validation requirements but are considered as a first indication concerning the properties of the new material.

Using materials with talc fillers, in the case of components that present aesthetic requirements, the weight reduction results that could be obtained range from approximately 5% to 10%. In some cases it was not possible to find materials able to satisfy the required properties and which, at the same time, had a lower density.

By shifting attention to different fillers, such as hollow glass microspheres, the potential performance is greater and results up to 30% in weight reduction can be achieved but, this type of material, it cannot be used on components contactable during crash because it is fragile, with consequent insufficient impact resistance and, therefore, does not guarantee adequate mechanical strength. To solve this problem glass fibres can be added but, during the moulding phase, they generate aesthetically unacceptable striping. In spite of everything, this material has already been used for a foamed dashboard on a higher segment. Finally, materials with natural fibre fillers have also been considered and the estimated weight reduction is just below the objective.

The results obtained regarding the materials can be further improved by considering other solutions for weight reduction such as component design and production technologies, since in these phases it is possible to optimize the exploitation of the material considering the performances required to the component.

The production technology most used in the automotive industry for the manufacturing of plastic components will be presented below. In particular, moulding technologies and related innovations will be considered, which have recently found space for their application in the automotive sector.

4. MANUFACTURING PROCESSES

The most important process employed for plastic products manufacturing is injection moulding. It is ideally suited to manufacture mass produced components that require precise dimensions and that can have complex shapes, indeed it is generally exploited in manufacturing thermoplastic components for automotive interior, and in particular also for dashboard components production. A short description of the fundamental concepts about injection moulding is going to be reported in the following chapter. Other manufacturing technologies, exploited in mass production, are blow moulding, vacuum forming and extrusion but these processes are more suited for easier geometries.

4.1. INJECTION MOULDING

Injection moulding consists in the injection of fused polymer, obtained from pellet or granules, into a mould cavity exploiting temperature, pressure and time as parameters that influence the final results, once the polymer is almost in the solid state again is possible to extract the moulded component. Typical mass quantity that can be injected during a cycle ranges from 20 g to 20 kg, this measure is called shot size.

The injection moulding machines, reported in Figure 4.1, can be generally decomposed in:

- **Plasticising and injection units**
  Their major tasks are to melt the polymer that has been introduced through the hopper, than accumulate it in the plastification chamber and at the right moment of the cycle to inject the melt into the cavity with the required quantity, timing and pressure and maintaining finally the holding pressure during the cooling phase.
- **Clamping unit**
  Its role is to manage the movements during the component ejection. During the filling and holding phases, it must hold the mould tightly to avoid flash; the provided clamping force can be mechanical and hydraulic and must be proportional to the component dimensions.
- **Mould**
  The mould can contain one or multiple cavities and distributes the polymer melt into them, shaping the part, cools the melt and ejects the finished product.

Generally injection moulding machines are categorised by their clamping tonnage that can range from tens of tons employed for example in the production of screw aesthetic covers production to 10.000 tons for car hardtops moulding. A different classification comes from the clamping unit driving system that can be hydraulic, mechanical and, more recently on smaller machines, electrical or hybrid.

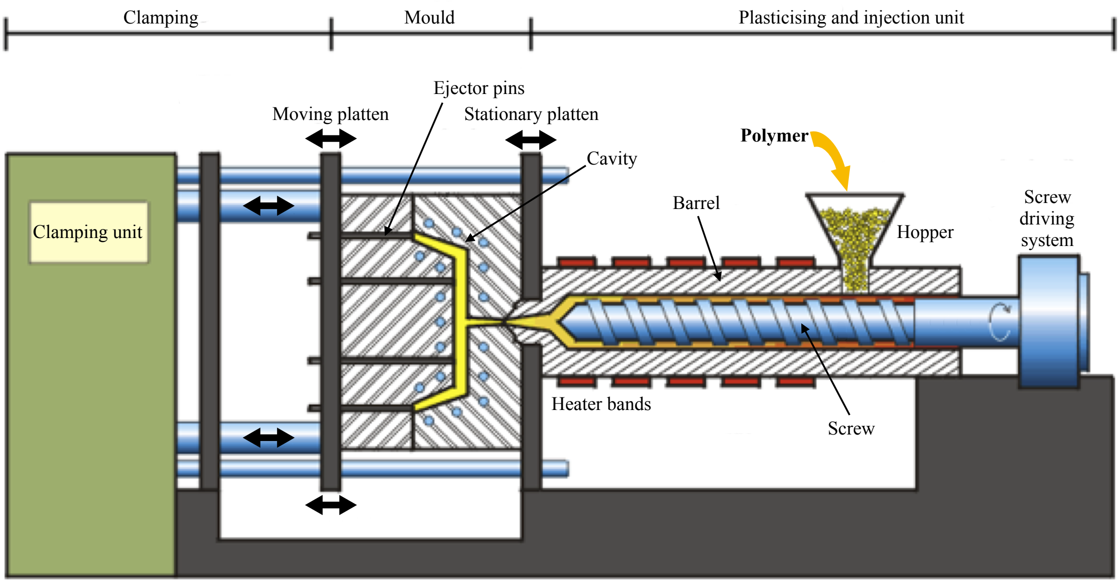

Figure 4.1. Injection moulding machine scheme

The injection moulding cycle can be split into different phases:

1. *mould closure*, the clamping unit moves the movable half of the mould;
2. *material injection* in the cavity thanks to injection unit forward movement, packing and holding phases during which, thanks to the pressure applied in the final part of the stroke, is possible to control the final properties of the component;
3. *cooling time* is needed since to extract a piece some small cylinders or dedicated shapes (ejectors) are exploited and these must work on almost solid surface, during this phase the screw starts rotating in the backward direction heating up to the right temperature the material and preparing the melt polymer for the next shot;
4. *mould opening*, the clamping unit moves the movable half of the mould;
5. *part ejection* exploiting the ejectors and/or robot to assist the operation.

Different defects and complications can occur during the injection moulding including component deformations and surface imperfections, a short list of the important problems is reported here below:

- *flow lines* are marks of a slightly different colour with respect to the adjacent area, generally caused by variations in cooling speeds of the component;
- *warping* is a permanent deformation of the component or part of it, that originates from an uneven shrinkage of different areas or incorrect extraction;
- *vacuum voids* result from bubbles of air that remain trapped in a moulded component thus creating air pockets near the component surface;
- *sink marks* are local depressions that generally appear on areas designed thick and flat of a component, when the inner portion of these areas shrinks pulls the material from the surface;
- *weld lines* can appear on the surface of a moulded part when the material flow splits into two or more directions than re-joining without the best characteristics (e.g. temperature, etc.) and creating therefore a weaker area, lowering the strength of the part;
- *flash* (called also burrs) is an excess of material that is flowed between the two halves of the mould or eventual movable parts and that remains attached to the component, it can be caused by the insufficient clamping force or not correct section parameters.

4.2. MICROCELLULAR INJECTION MOULDING

A manufacturing process that the automotive industry has been considering in recent years is the microcellular injection moulding: it consists in the development of microcellular plastic concept that could be applied to mass production. In particular, the interesting aspects for the automotive sector are the possibilities of reducing weight and cycle time while maintaining the toughness of the component.

All plastic foams can be sorted, unrelatedly to the processing technology, according to different principles, as an example it is possible to classify plastic foams by their cell dimension; when it is in the order of tens of micrometres, it is possible to talk about microcellular foams. An example of this structure is represented in the micrograph in Figure 4.2.

The first approach to microcellular foams has been done in the 80s at Massachusetts Institute of Technology (MIT); the requirements for the technology were to reduce the amount of plastic employed in the production of components without compromising the properties and maintaining the possibility of replicating existing products shapes. Therefore the idea that was at the basis of the microcellular plastic development were the introduction of tiny voids, with dimension comparable or smaller with respect to that of critical defects already present in plastic in order to maintain the mechanical properties.

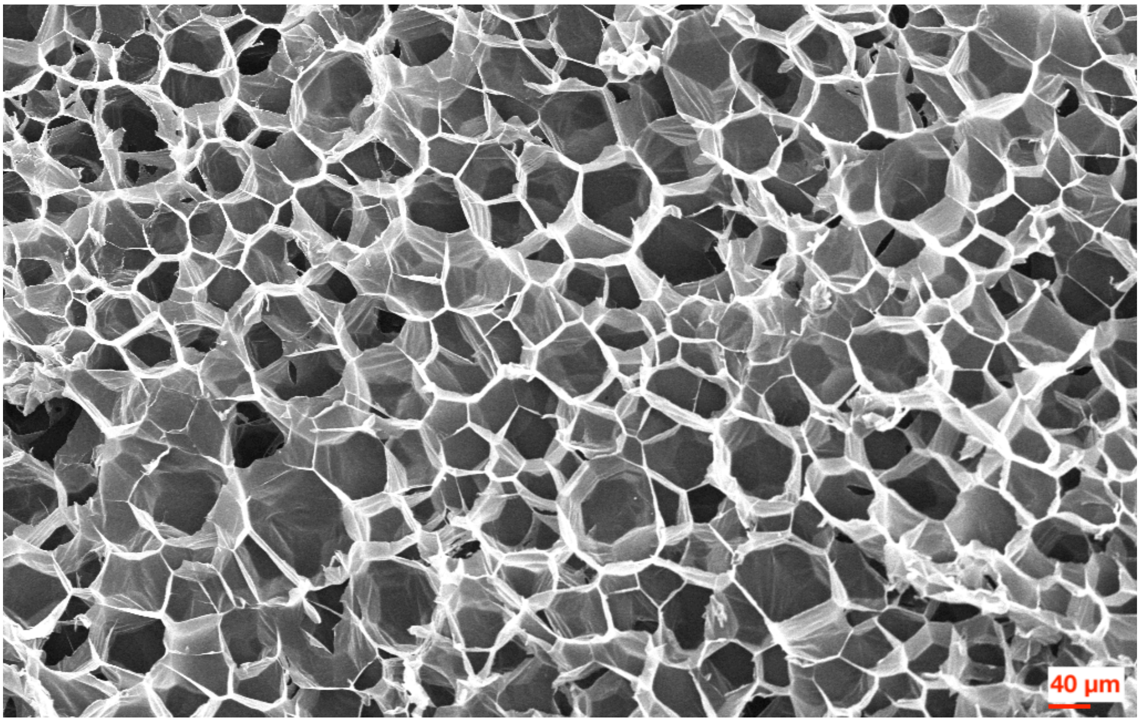

Figure 4.2. Microcellular plastic micrograph

To create this structure of micrometric cells, a gas must be incorporated into the polymeric matrix and to do this, the polymer undergoes a special foaming process based on gas-foaming compound. The latter is also known as blowing agent, which can either be chemical or physical, depending on whether the gas is introduced by chemical reactions or physically.

To obtain the desired characteristics a homogeneous polymer-gas solution is required, with high cell density and small and uniform cell dimensions. The solution uniformity is achieved exploiting diffusion and mechanical mixing in case of industrial applications; the type of polymer and the degree of crystallinity, the gas saturation pressure and temperature affect the final solubility of the gas in the polymer.

The basic process, originally identified, was based on diffusion, but the problem with this technology was that it could not be applied to the industrial scale.

In the industrial application, also called continuous microcellular processing, the previous concept has been developed in order to manufacture products that can benefit of the advantages identified over the years of microcellular foams.

In particular weight reduction and cycle time reduction are the most attractive benefits from industrial point of view but also production cost reduction and more design freedom with respect to conventional injection moulding technology are allowed. Moreover lower internal stresses, leading to smaller warpage, and superior thermal isolation can be listed in the pros. Unfortunately a remarkable obstacle to a wider possibility of application is represented by the general tendency to mechanical properties deterioration and low surface quality. (Trexel, 2019), (Negri Bossi Spa, 2019), (Wong, Guo, Kumar, & Park, 2016), (Der Chien, Chen, Lee, & Huang, 2004)

For this reason over the years, additional technologies have been developed, such as injection moulding with mould opening, microcellular co-injection moulding and the Rapid Heat Cycle Moulding and Gas Counter Pressure Moulding Technology, to improve skin quality. (Trexel, 2019), (Wong, Guo, Kumar, & Park, 2016) A brief explanation of the different processes mentioned before is reported below:

- **Microcellular Co-injection Moulding**
  It is a two-step process where a first injection of plastic melt to form solid un-foamed skin and than a second injection of polymer-gas solution to foam the core are done;
- **Rapid Heat Cycle Moulding (RHCM)**
  It consists in a rapid heating during the first phases of injection, in order to avoid premature solidification of the polymer, and a sequent rapid cooling of the mould to eject the part;
- **Mould Opening (Core-Back) Injection**
  This technology enables the control of mould position during the different phases, first a full shot of polymer gas solution is injected and kept packed to solid skin formation end, finally the movable half of the mould retracts of a predetermined thickness and foaming occurs. Unfortunately this technology is affected by a high limitation in component geometry;
- **Gas Counter Pressure Moulding Technology (GCP)**
  By controlling a pressurised gas in the mould cavity, this counter-pressure encountered by the polymer control the cell expansion at flow front enabling a better surface quality.

4.2.1. Physical foaming

In microcellular injection moulding process the gas can be incorporated in the polymer by mean of a physical introduction and generally the nucleation of cells happens when the polymer-gas solution experiences a depressurisation; this means that the foaming starts at the gate and continues with cell growth during foam expansion, filling the mould cavity. Typically the rapid cooling of material that comes in contact with mould surfaces forms a solid skin layer, the remaining portion of inner foamed structure is stabilised during the final cooling stage, before mould opening and part ejection. Figure 4.3 reports a schematic of the different phases that lead to cell creation.

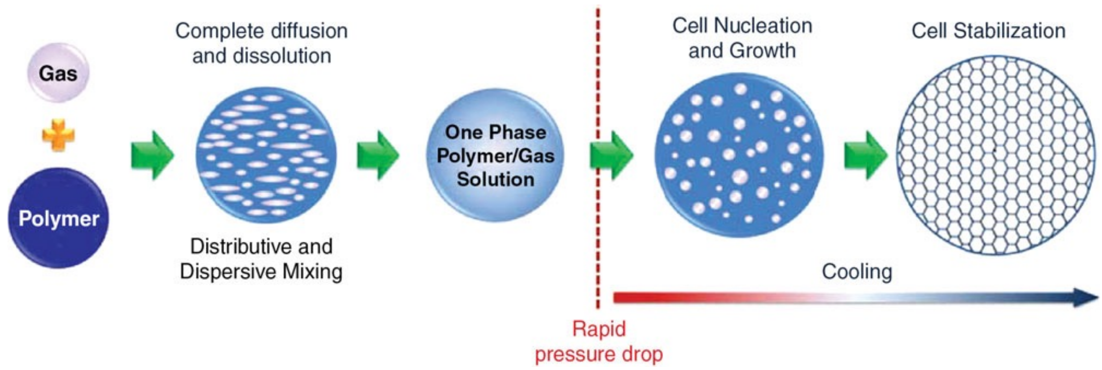

Figure 4.3. Typical microcellular physical foaming process

Cell nucleation, which can be affected by shear stress and typology of blowing agents, consists in the cell creation that is generally achieved when the polymer-gas solution undergoes a depressurisation causing a decrease of solubility. Whereas mass transfer between cells drives cell growth, generally wall rupture between adjacent cells is called cell coalescence.

Different patents have been submitted on machinery to produce microcellular foams by injection moulding, the first that is going to be reported is by Trexel and than a second one by injection moulding machines producer Negri Bossi.

4.2.1.1. Trexel MuCell®

The microcellular foaming technology originally developed at the Massachusetts Institute of Technology, has been marketed since 1995 under the registered trademark MuCell® by Trexel Inc. which obtained an exclusive license.

The equipment for MuCell® injection moulding machine consists of:

- nitrogen (N_2) or carbon dioxide (CO_2) supply tank(s);
- supercritical fluid (SCF) metering and control system;
- supercritical fluid injector;
- a special plasticising unit that includes a dedicated screw profile with back and front non-return valve and a shut off nozzle.

A substance is in the supercritical state when its temperature and pressure are above the respective critical values, where there are no distinct liquid and gaseous phases but the fluid has intermediate properties between a liquid and a gas. In Figure 4.4 the carbon dioxide pressure-temperature phase diagram is reported: the separation between gas and liquid regions is the boiling point and culminates in the critical point, after which only the supercritical fluid is present for higher pressures or temperatures.

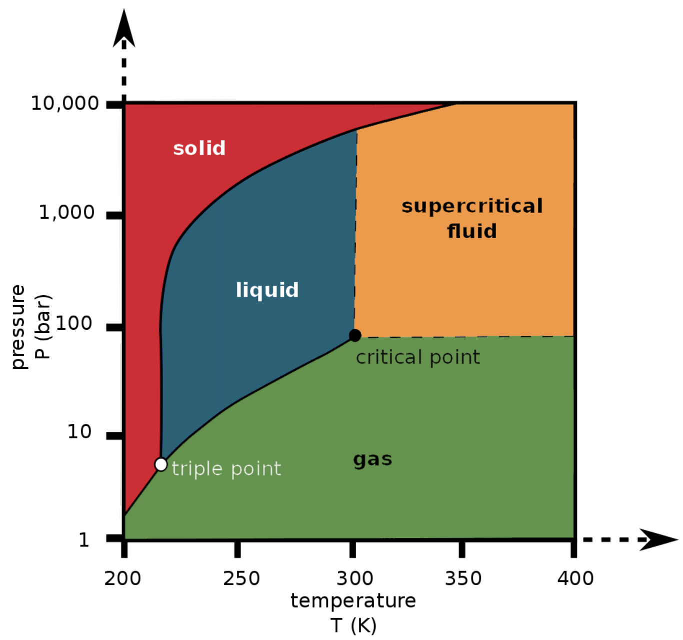

Figure 4.4. Carbon dioxide pressure-temperature phase diagram

Figure 4.5 provide a basic scheme of MuCell® injection moulding machine equipment. It is possible to buy dedicated machines or implement the MuCell® technology on existing machineries but at the condition that some modification must be done: in particular in order to install the supercritical fluid injector a modification of the injection barrel is necessary, as well as a dedicated screw tip must be employed.

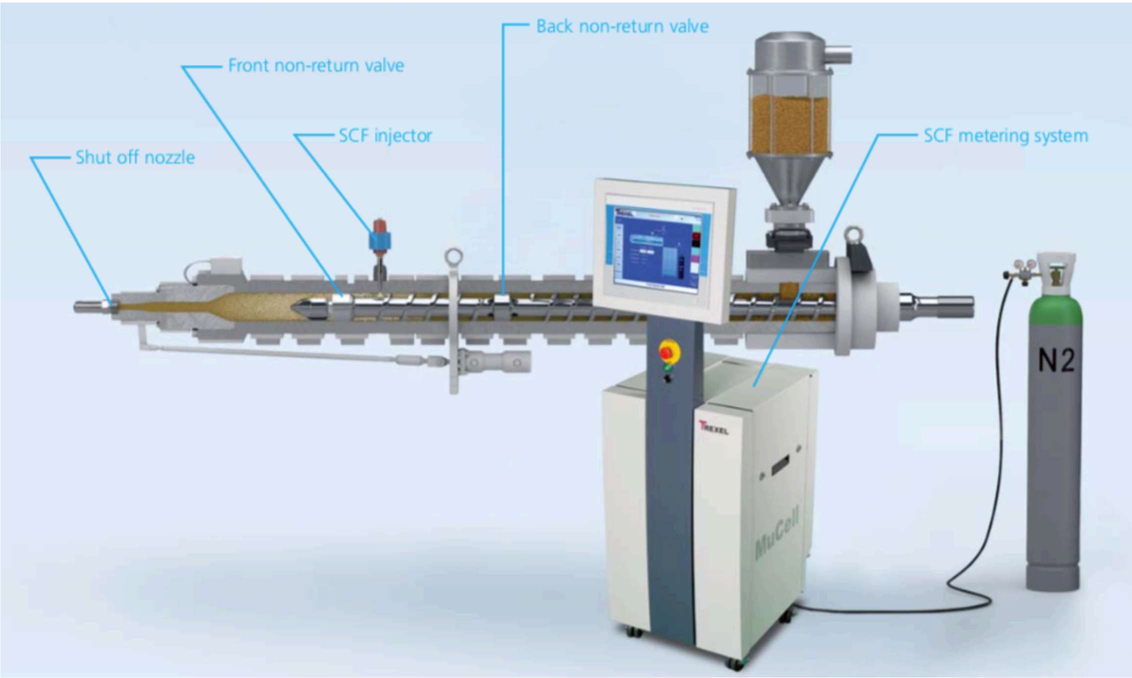

Figure 4.5. MuCell® foaming equipment

The different phases typical of Trexel's MuCell® process, can be summarised by the following points:

1. the shut off nozzle is kept in the closed position while the movement of the screw melts and mixes the polymer and the additives fed by the hopper bringing them towards the tip of the screw;
2. during plasticisation, in the last part of the screw backward stroke, appropriate amounts of supercritical fluid at high pressure, typically nitrogen or carbon dioxide, are introduced into the polymer by means of the injector mounted on the plasticizing barrel;
3. the gas in the supercritical state dissolves in the melted polymer forming a homogeneous single-phase solution thanks to the action of the special mixing section of the plasticizing screw. The shut off nozzle and the non-return valve retain the gas in the polymer;

4. at this point the shut off nozzle is opened and the screw moves forward, allowing the injection of the polymer-gas solution into the cavity of the mould; due to the pressure drop the gas expands forming a microcellular structure. The packing and holding phases can be replaced by cell growth, which can result in a more uniform pressure in the whole cavity;
5. finally the mould is opened to eject the part and the next cycle is prepared.

(Trexel, 2019), (Wong, Guo, Kumar, & Park, 2016)

It is known that foam density affects the material general properties; as far as the impact performances are concerned, the overall trend shown by different researches is the non-variability of IZOD impact strength when the relative density values lies around 0,9 corresponding to a density reduction of 10%, while a reduction of impact strength can be observed when lower values of relative density are considered. (Wong, Guo, Kumar, & Park, 2016)

These considerations about mechanical properties are confirmed by the suggested percentages of density reduction given as design guidelines by suppliers and the more distributed pressure make it possible the optimisation of the design in areas that need to be structural, as an example the rib-to-wall ratio can be maintained at 1:1 with respect to the traditional 1:3, which can lead to greater weight savings allowing a possible final result of more than 20% compared to the solid counterpart. (Trexel, 2019)

Figure 4.6 resume the potential results of the application of MuCell® process and possibly more general physical foaming.

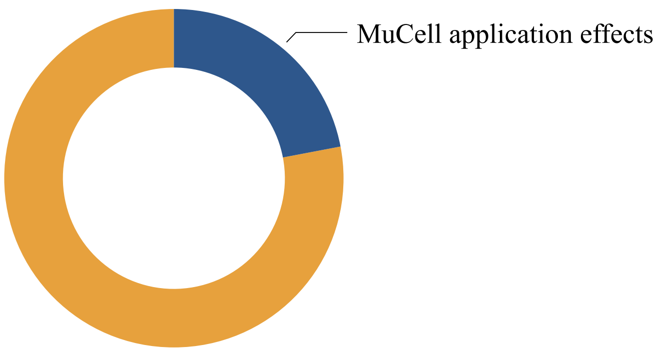

Figure 4.6. Qualitative representation of weight reduction that can be achieved employing MuCell® process

Furthermore the supercritical fluid dissolved in the polymer can act as a temporary plasticiser reducing the density of the polymer; in this case it would be possible to reduce mould temperatures, shortening the cycle time as qualitatively reported in Figure 4.7.

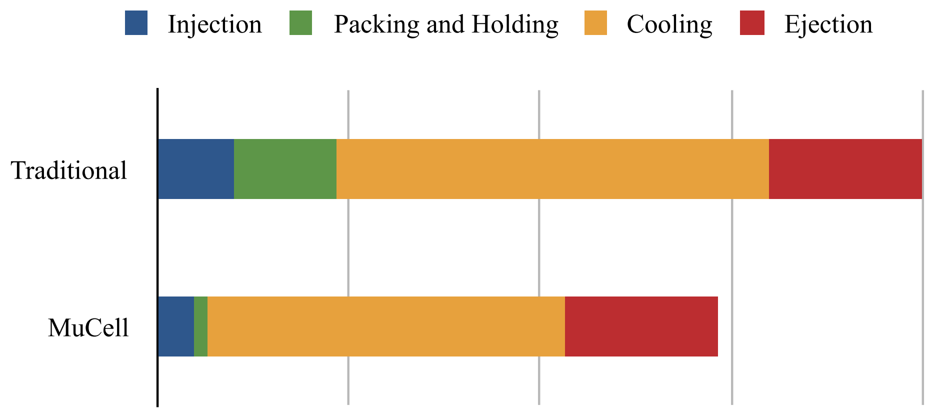

Figure 4.7. Qualitative representation of cycle time reduction that can be achieved employing MuCell® process

Considering the aesthetic properties, reduced surface quality of foamed component, generally characterised by rough skin or swirl marks, can be traced back to an excessive shear stress through the gate, as suggested by MuCell's guide provided by Trexel. (Trexel, Inc., 2015) This drawback together with the machinery modification required have been the main limitations for the diffusion in past years and that relegate up to now its application to non-aesthetical components.

Some examples of MuCell® application have been found: a sun roof module of 2010 American segment E car that thanks to the integration of four pieces design achieved a 12% of weight and 15 seconds of cycle time reduction. A different example can be represented by a door panel for German segment E car in 2009 where the MuCell® application allowed an important cycle time reduction of 50%. Speaking of instrument panel, a 0,5 kilograms reduction has been reached by an American carmaker on a compact SUV, same result obtained on the best selling car in Europe. (Trexel, 2019)

4.2.1.2. Negri Bossi Foam Microcellular Moulding Process

In 1947, which is the year of foundation, Negri Bossi was one of the first companies to produce injection moulding machines in Europe and it is now, one of the leading injection moulding machine producers around the world. They presented in 2017 the Foam Microcellular Moulding Process® (FMC); the main goal of this technology was to obtain microcellular foams without applying major changes to the traditional components of the injection moulding machine and still obtaining a reliable and repeatable process.

An additional requirement for the Foam Microcellular Moulding Process® that Negri Bossi considered, was the possibility to retrofit on existing machines the proposed technology and do not limit the applicability to newer one.

The equipment of Negri Bossi's Foam Microcellular Moulding Process® includes:

- nitrogen (N_2) tanks;
- proportional control valve;
- Negri Bossi screw with special profile;
- pneumatic/hydraulic nozzle;
- software interface.

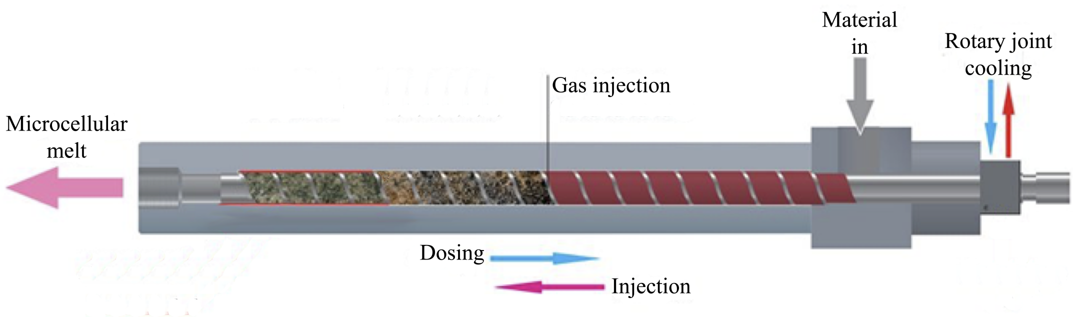

Figure 4.8. Negri Bossi FMC system

The Foam Microcellular Moulding Process® exploits a special screw, which has a channel in the centre of the section for the gas passage that is released by means of a series of holes in the metering zone. (Plastics Technology, 2019) It is thanks to this modification that the company has been able to adapt the foaming technology to older machines.

This system has not been employed into automotive industry yet but during its presentation it was exploited for a mini pallet production, reducing the piece weight by 20% while guaranteeing mechanical performances; this result seems to be a promising perspective if confirmed also on automotive components.

4.2.2. Chemical foaming

While in physical foaming the gas is injected in the screw zone, in the case of chemical foaming the gas is produced thanks to the reaction of a chemical product mixed with the polymer.

The chemical products used for producing microcellular plastic, called also chemical blowing agents (CBA), are solid substances that decompose once the activation temperature and pressure are reached during the process, releasing gas as a product of chemical reaction. Chemical blowing agents are added to the polymer as masterbatches and generally include nitric compounds or sodium bicarbonate that produce nitrogen (N_2) or carbon dioxide (CO_2) after decomposition.

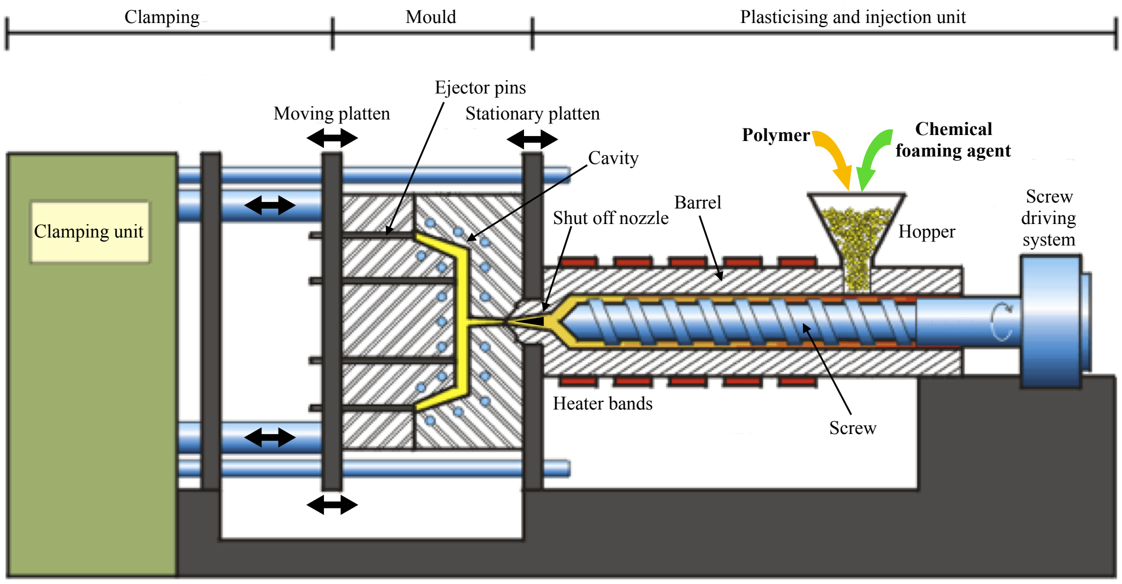

Figure 4.9. Chemical foaming

The masterbatch is a particular type of pellet, with a relatively high concentration of additives (for example pigments or in this case the foaming agent) with respect to the concentration of the additives desired in the final product.

The masterbatch is mixed with pellets of pure polymer during material processing (for example during injection moulding), their use alleviates the issues with the additive or colorant aggregation or insufficient dispersion. Indeed generally the additives must be present in very small percentages (even parts per million) in the finished product, so without the use of masterbatches the additives should be inserted in the form of powder, with consequent difficulties in the dosage (it is easier to weigh a few grams of masterbatch rather than few micrograms of powdered additives) and mixing (the masterbatch pellets mix better with the other pellets than the powdered additive).

A general distinction can be made between endothermic and exothermic blowing agents:

- **Endothermic blowing agents**
  They require and consume a certain amount of heat and energy to start the decomposition reaction. They allow the foaming process to be controlled by regulating heat transfer during the reaction time;
- **Exothermic blowing agents**
  If they release both gas and energy upon reaching a certain temperature. Once the exothermic reaction has begun, it cannot be influenced, which therefore continues spontaneously.

The possibility of keeping the injection moulding machine or more generally the production line unchanged, although suppliers suggest to exploit a machine with shut off nozzle, is the main advantage that can be identified in the use of chemical blowing agents together with the different points in favour of microcellular foaming. But this technique is not free from drawbacks since the chemical reaction that characterises the decomposition of such blowing agents can leave some residual by-products that over time could interact with the polymer and subsequently make recycling of the component at the end of its useful life difficult; this is not true for all chemical foaming agents but could be an important issue that must be considered during the design stages.

The typical dosage suggested by the suppliers of chemical foaming agents is a small percentage by weight of effective component (generally 0,3% to less than 5%) for application to injection moulding with the final objective of weight reduction; therefore car manufacturers could exploit this technique to reduce the weight of many plastic components of the dashboard and more generally of the car interior still having the possibility to meet the final performances required. It is important to underline that the results that can be expected in weight reduction can be around 15% to 20% using the suggested product percentages. (Clariant, 2019)

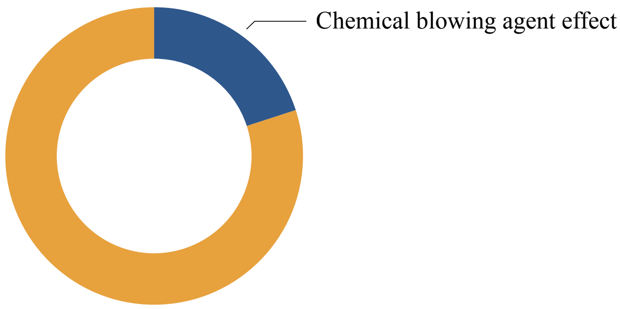

Figure 4.10. Qualitative representation of weight reduction that can be achieved employing chemical blowing agents

In case of physical foaming cell nucleation can be induced exploiting the so-called nucleating agents. These provide a starting point from which the foam cells can start to expand, more nucleation points mean the possibility that more cells are formed and therefore an expected final result of average cell size which is smaller.

It is possible to distinguish basically two categories of nucleating agents:

- *passive nucleators,* which include solid materials with fine particle size. A typical example would be talc. The efficacy of this typology is affected by the shape and dimension of the particles.
- *active nucleation* is the one that can be provided by chemical foaming agents as the gas generated by their decomposition can provide the cell nucleation starting point, as schematised in Figure 4.11.

The final structure expected with the application of active nucleators should be with smaller and more uniform cells with respect to the one obtained with passive nucleators and without them.

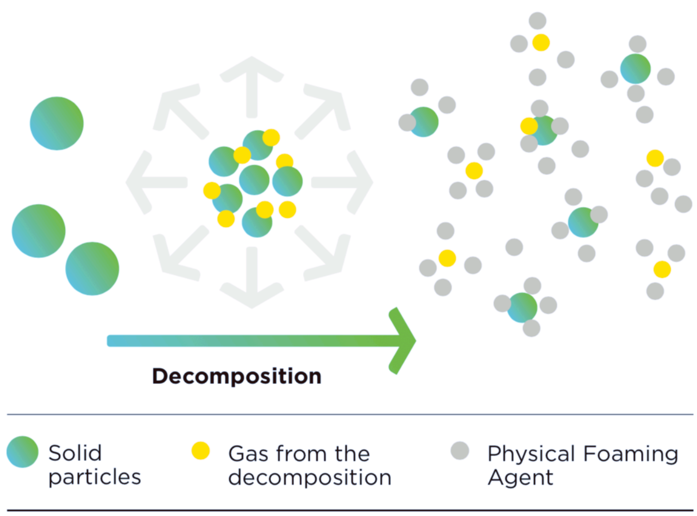

Figure 4.11. Chemical blowing agents active nucleation

Some work on chemical foaming technology have been done by a Tier 1 supplier for different structural non visible parts since 2013, with a recent positive validation on a structure of the upper dashboard hypothesized of polypropylene reinforced with natural fibres.

A German carmaker, with an automotive components and systems suppliers and an important petrochemicals manufacturer, at the end of 2017 employed the chemical foaming together with the Coreback technology to reduce the weight of an instrument panel carrier realised with long glass fibres reinforced polypropylene. They have been able to reduce the mould cavity thickness, that generally is about 2,8 millimetres, to 1,9 millimetres allowing than the foam to expand to 4 millimetres thanks to the Coreback adding no weight. The result obtained finally is 15% reduction in weight with respect to a comparable solid plastic component but it is not specified is the result is obtained on tests or on production components.

4.3. CONSIDERATIONS ON PRODUCTION PROCESSES ANALYSIS

In this chapter the various opportunities for reducing weight have been taken into consideration by modifying the moulding process and in particular injection moulding since it is generally used for the production of cockpit components.

It was found that an opportunity for weight reduction is represented by the application of microcellular foams and different solutions have been considered. The first identified consists in the MuCell®, a modification to the injection moulding machines that offers the possibility of directly injecting a gas, defined physical foaming agent, into the plasticizing unit. This patented process involves the installation of a gas injection port on the injection barrel and a special screw. The supplier indicates that weight reduction results of around 20% can be achieved or exceeded, but to accomplish these objectives, a specific mould design is also required.

Another similar technology is the Foam Microcellular Moulding Process® (FMC), again based on the injection of a gas into the plastification chamber. The main difference from the MuCell® is that the FMC® solution does not require the modification of the injection cylinder but only the installation of a dedicated plastification chamber. It is important to highlight that in this case a dedicated mould design is not required.

The last solution considered is the chemical foaming with which it is possible to obtain microcellular foams, thanks to the decomposition of a blowing agent, which is activated when specific temperature and pressure are reached. In this case, dedicated equipment should not be required to obtain the micro-cellular structure, but the fact that the actual use in the automotive production has not been confirmed is an indication of the complexity of the process. Furthermore, the effectiveness of the chemical reaction also depends on the correct mixing between polymer and foaming agent in the hopper.

The three solutions identified to achieve a weight reduction result greater with respect to the objective will be tested to confirm the feasibility and applicability from a technological point of view.

5. Conclusions

The objective of this thesis is to find opportunities to reduce plastic components weight in automotive applications by 10%, guaranteeing the required specifications and the previously assured performances. To start the analysis, the state of the art of the C-segment plastic interiors, as the best selling, was taken into consideration, and in particular the dashboard that constitute most of its weight.

The first analysis focused on the materials used for the production of the dashboard and its various components. The materials were compared using some characteristics chosen on the validation requirements that a dashboard must satisfy. It is important to emphasize that although a material complies with these parameters, it is not guaranteed that if replaced it will behave like the one in use. After examining these components and their materials, the estimated weight reduction is around 5% in the case of talc or natural fibre fillers. A better result can be obtained if hollow glass microspheres and glass fibres are considered as filler, but in this case, aesthetic problems may arise (for example stripes).

The results obtained can be improved by considering new technologies that can offer the opportunity to reduce weight. Injection moulding was analysed first, as it is the one usually employed for the production of cockpit plastic components and an opportunity has been found in microcellular foams.

Several approaches to obtain this internal structure have been presented: among these the MuCell®, a physical foaming technology that requires dedicated injection moulding machines to inject the gas into the melted polymer, and a more recent example of physical foaming, the Foam Microcellular Moulding Process® (FMC), was considered. Finally, the chemical foaming, which uses solid substances mixed with the polymer, which decompose at a given temperature generating the gas.

The three solutions identified to achieve a weight reduction greater than the objective will be subjected to extensive tests, moulding a constructive detail of the interior of the car, the results of which will be used to confirm the feasibility and applicability from a technological point of view.

A dedicated study can be carried out to understand the possibilities offered by the different assembly processes, as happened with the transition from vibration welding to ultrasonic welding which allowed a weight saving of almost 2 kg on a dashboard. In this case the reduction in weight is derived from the possibility of using reduced welding tracks thicknesses during the design phase, avoiding anyway aesthetic defects that would otherwise have appeared with vibration welding. The one reported is an example of an important weight reduction result that could be further improved by considering innovative assembly technologies.

Clearly, in order to maximize the benefits of what have been examined, it is essential to combine product and process engineering with material science so that it will be possible to reduce weight while maintaining and improving the components performances.

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