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STUDY OF THE BEHAVIOR OF A COMPOSITE MATERIAL USED IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The purpose of this study is to analyze a case of failure of composite materials that are used in the automotive industry. This work has allowed us to identify the following points: Theoretical and practical information that concern composite materials, in order to be able to produce mechanical parts. On the other hand; to acquire the static characteristics of rupture of these materials (ABS and Acrylic) through a numerical simulation using the software SOLIDWORKS

We apply to these two materials three static loads, which begin with 1000N and end with 3500N, where we notice that the first material ABS is more resistant than the other one (Acrylic) to the load 3500N and this according to the numerical simulation by software SOLIDWORKS.

KEYWORDS: *Composite Materials, Damage, Impact, Numerical Simulation*

Article History

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INTRODUCTION

Composite materials are increasingly replacing traditional metals in most industrial applications. They are used in the manufacture of both technical textiles and composite materials, and are used to develop these new advanced materials.

With a continuously expanding market, the composite materials sector is showing continuous growth. Thanks to this assembly process associating a fiber to a matrix, industrialists have the opportunity to develop materials with a new design, lighter, stronger while ensuring very high performance.

Composite materials are used in many applications and are increasingly flooding our daily lives. In addition to aeronautical and aerospace uses, they are also present in the civil engineering, automotive, shipbuilding, wind power, sports, etc. sectors. In this part we will speak about the use of composite materials in the industry in general and its use in the automotive industry in particular.

A priori, due to their intrinsic characteristics, composite materials, with thermoplastic and/or thermosetting matrices, present three major handicaps compared to metallic materials to allow a production of parts technically and economically compatible with the rates (one car per minute) and the series (1000 to 3000 vehicles/day) encountered in the automotive industry, namely:

- A price per kilogram often higher (especially compared to steel)
- Weaker intrinsic mechanical characteristics: flexural modulus, breaking strength, limit temperatures, etc.
- Processes of implementation of the finished parts often slow: except for the processes of except for injection processes, whose rates, costs and tool life are close to those used in metallurgy (2000 to 3000 parts/day), the other processes commonly used, mainly compression, only allow low or medium rates (from a few parts to 350-400/day, per tool). In this case, the tools, requiring only relatively low investments, have a more limited life span.

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COMPOSITES IN THE AUTOMOTIVE INDUSTRY

The automotive market is an important market for the materials industry. In Europe, about 12 million vehicles, with an average mass of 1,000 kg, are produced annually, representing about 12 billion kg of materials. [13]

If in its beginnings, about 100 years ago, an automobile was mainly made of wood and steel, today it gathers many materials belonging to the following large families:

- Ferrous materials: cast iron, steel, sheet metal (about 70% of its mass)
- Non-ferrous materials: aluminum, copper, magnesium (about 5%)
- Mineral materials: glass, ceramics (about 4%)
- Organic materials: paints, adhesives, textiles, fluids, rubbers Thermoplastics and thermo sets reinforced or not by fibers (glass, carbon, armed, natural) or mineral fillers (about 20%). Organic composite materials with thermoplastic or thermosetting matrices reinforced by short or long fibers, generally glass, appeared in the automotive industry in the 1960s and 1970s. Although they are now used almost exclusively to satisfy certain functions, their usage rate does not exceed 10-15% depending on the vehicle. [13]

We Propose to Show

- The interest of using composite materials in the construction of an automobile from the point of view of the manufacturer and its final customer and to highlight the difficulties to be overcome to increase their use.
- The various fields of use in the automobile; for each of them will be examined the evolution of the quantity of composites used compared to the learning curve, the great families product/implementation/assembly method, the advantages/disadvantages, the particular expectations and the constraints.
- The foreseeable evolutions in the future and the problematic linked to the passage from a mono-material vehicle (steel represents more than 70 %) to a multi-material vehicle (steel becomes a minority).

Figure 2 shows the main degradations of composite materials come from the mechanical actions they undergo. Indeed, the network of structured interfaces of the laminates (especially with long fiber) is particularly exposed to degradations because these interfaces are located between components having different mechanical properties. During stresses, the damage tends to follow this network of fibers. Different phenomena can also occur in the folds of this network depending on the direction of the stress parallel to the fibers or not.

Impacts: Following an impact, the length, width and depth of the damage will be specific to the object that has been impacted. Composites being nowadays much more present on a vehicle, they are consequently more subjected to shocks. It is this type of damage that we are most often confronted with in automotive repair. [14]

Figure 1: Example of An Automotive Part Made of Composite Materials.

Figure 2: Impacts on the Bumper.

DESIGN AND SIMULATION OF A VEHICLE ELEMENT (BUMPER)

Introduction

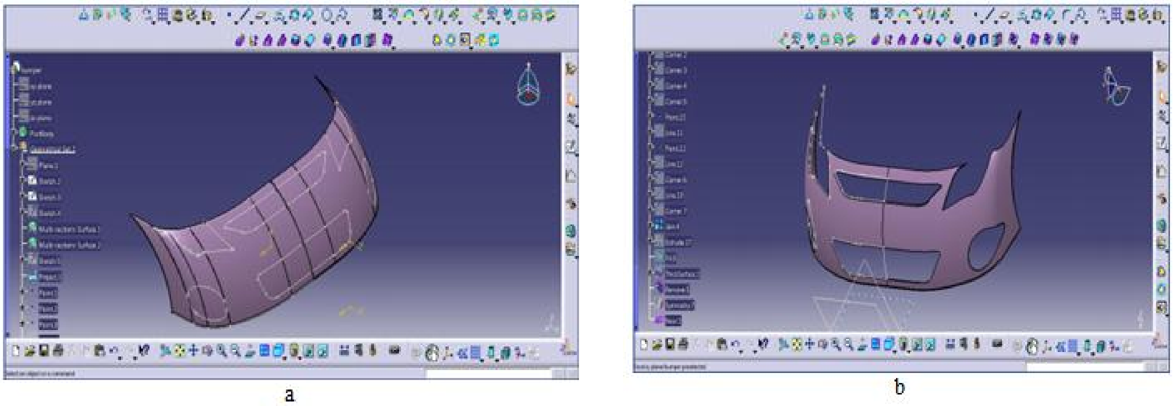
Computer or digital simulation refers to the execution of a computer program on a computer or network to simulate a real and complex physical phenomenon. Scientific numerical simulations are based on the implementation of theoretical models often using the finite element technique. They are therefore an adaptation of mathematical modeling to digital means, and are used to study the functioning and properties of a modeled system as well as to predict its evolution. It is also called numerical calculation. The graphic interfaces allow the visualization of the results of the calculations by synthetic images.

Design of a Bumper

The design is made by CAD software passing by different stages to make the final design of the bumper of a Toyota vehicle see figure 3 a and b.

The Materials Chosen for the Study Are ABS and Acrylic

- **ABS:** Acrylonitrile butadiene styrene (ABS) is a thermoplastic polymer that is impact resistant, relatively rigid, lightweight and moldable. It belongs to the family of styrene polymers.
- **The Acrylic Fiber:** it is produced by the polymerization of the acrylonitrile molecule (CH2=CH-CN). It is characterized by a soft and silky touch, infeutrable, of a great lightness, has stability with the folds, and loses little of its properties in aqueous phase.



a b

Figure 3: a and b. Design of a Toyota Shock Absorber Using CAD Software.

SIMULATION

Study Parameter

Table 1: Study Properties of the Bumper

Study Name	Study3
Type of analysis	Static analysis
Mesh type	Mesh volume
Thermal Effects:	Activated
Thermal option Include	thermal loads
Zero deformation temperature	273 Kelvin
Include fluid pressure calculated by SolidWorks Flow Simulation	Disabled
Solver type	FFE Plus
Stress Stiffening:	Disabled
Low stiffness:	Disabled
Inertial relaxation:	Disabled
Incompatible contact options	Automatic
Big Move	Activated
Check external forces	Activated
friction (e)	Deactivated
Adaptive method:	Disabled
Results folder	Document SolidWorks

Properties of Each Material

Table 2: Abs Material Properties

Model Reference	Properties
	**Name:** ABS **Model Type:** Linear elastic isotropic **Default Ruin Criterion:** Von Mises stress max. **Tensile Limit:** 3e+ 007 N/m^2 **Modulus of Elasticity:** 2e + 009 N/m^2 **Poisson's Ratio:** 0.394 **Density:** 1020 kg / m3 **Shear Modulus:** 3.189e + 008 N/m^2

Table 3: Properties of Acrylic Material

Model Reference	Properties
	**Name:** Acrylic (impacte dium-high) **Model Type:** Linear elastic isentropique **Criterion Default of Ruin:** by von stress Max. **Yield Strength:** 4.5e + 007 N/m^2 **Traction Limit:** 7.3e + 007 N/m^2 **Modulus of Elasticity:** 3e + 009 N/m^2 **Coefficient of Fish:** 0.35 **Density:** 1200 kg / m3 **Module of Shear:** 8.9e + 008 N/m^2 **Coefficient of Thermal Expansion:** 5.2e-005 / Kelvin

External Actions

Table 4: Boundary Conditions

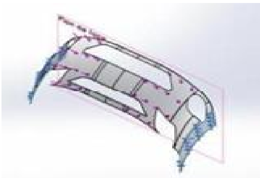
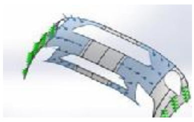
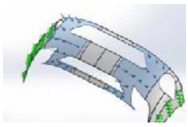
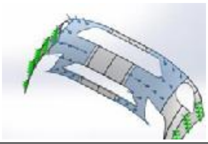
<table>
<tr><th>Name of the Displacement Imposed</th><th>Displacement Image Imposed</th><th colspan="3">Details of the Imposed Displacement</th></tr>
<tr><td>Geometry of Reference</td><td></td><td colspan="3">Entities: 2 faces, 1 map(s)
Reference: Front shot
Type: Use geometry Reference
Imposed Displacement: 0.1, 0.1, 0.1
Units: mm</td></tr>
<tr><th colspan="5">Resulting Forces</th></tr>
<tr><th>Components</th><th>X</th><th>Y</th><th>Z</th><th>Resultant</th></tr>
<tr><td>Reaction Force (N)</td><td>0.24398</td><td>2081.1</td><td>1966.9</td><td>2863.59</td></tr>
<tr><td>Moment of reaction (N • m)</td><td>0</td><td>0</td><td>0</td><td>0 N.m</td></tr>
</table>

Table 5: Charge Imposed

Name of Loading	Image of Loading	Loading Details
Force-1		**Entities:** 2 face (s) **Type:** Normal Strength **Value:** 1000 N
Force-2		**Entities:** 2 face (s) **Type:** Normal Strength **Value:** 1500 N
Force-3		**Entities:** 2 face (s) **Type:** Normal Strength **Value:** 3500 N

Mesh Information for Both Materials

Volume Mesh Type

Table 6: Mesh Type

Type of Mesh	Solid Mesh
Maneler used	Mesh based on curvature
Jacobian's points	4 Points
Maximum item size	121.491 mm
Minimum element size	24.2982 mm
Meshing quality	Medium quality mesh

Information on the Mesh of the Structure

Table 7: Information on the Mesh

Total number of nodes	7657
Total number of items	20380
Maximum aspect ratio	319.35
% of elements with a ratio aspect <3	26.8
% of elements with aspect ratio> 10	18.2
Duration of creation of the mesh (hh; mm; ss):	00:00:07

Forces and Moment Resulting Forces

Table 8: Reaction Forces

Set of Units	Selections	Sum X	Sum Y	Sum Z	Resulting	Strength	Material
Whole Model	N	0.27334	1388.81	1311.4	1910.15	1000	ABS
Whole Model	N	0.43621	2078.98	1966.7	2861.84	1500	
Whole Model	N	0.09404	3266.42	3089.9	4496.35	3500	
Whole Model	N	0.03026	1387.26	1311.3	1908.93	1000	Acrylic
Whole Model	N	0.24391	2081.15	1966.9	2863.59	1500	
Whole Model	N	6.09642	4874.35	4605.5	6706.01	3500	

Reaction Moments

Table 9: Reaction Moments

Set of Units	Selections	Sum X	Sum Y	Sum Z	Resulting	Strength	Material
Whole Model	N.m	0	0	0	0	1000	ABS
Whole Model	N.m	0	0	0	0	1500	
Whole Model	N.m	0	0	0	0	3500	
Whole Model	N.m	0	0	0	0	1000	Acrylic
Whole Model	N.m	0	0	0	0	1500	
Whole Model	N.m	0	0	0		3500	

RESULTS OF STUDY 1ST MATERIAL ABS FORCE APPLIES AND 1000N

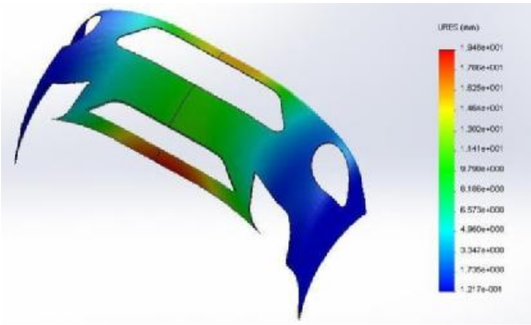
Table 10: Constraint of Von Mises for ABS 1000N

Name	Type	Min	Max
constraints	**Constraint of:** VON Mises	1.86802e-007 N/m^2 **Node:** 1351	2.20426e+007 N/m^2 **Node:** 6

Note: The values of the Von Mises are
Min: 1.86802e-007 N/m^2
Max: 2.20426e+007 N/m^2

Table 11: ABS Displacement 1000N

Name	Type	Min	Max
displacements	**URES:** Displacement Resultant	0.121697 mm **Node:** 5396	19.4762 mm **Node:** 316



Note: The resulting displacement values are
Min Displacement: 0.121697 mm
Max Displacement: 19.4762 mm

Table 12: ABS Deformations 1000N

Name	Type	Min	Max
Deformations	**ESTRN:** Deformation Equivalent	8.62892e-017 **Item:** 10424	0.067896 **Item:** 7263

Note: The equivalent deformation values are
Min Deformation: 8.62892e-017
Max Deformation: 0.067896

Table 13: ABS Deformations 1000N

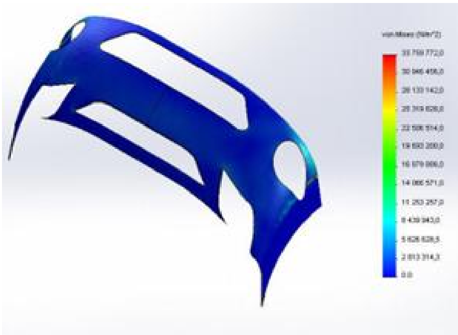
Name	Type
Displacement	Distorted model

Model of the material ABS on displacement and distortion worthless

Force Applies and 1500N

Table 14: Von Mises Constraint for ABS 1500

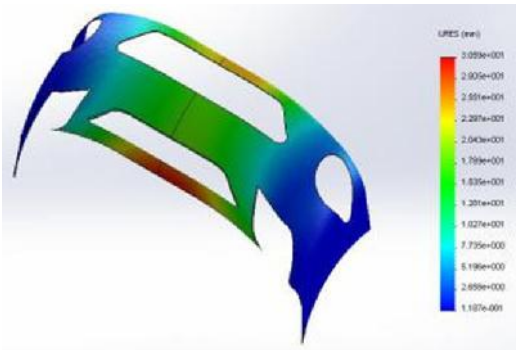
Name	Type	Min	Max
Constraints	**Constraint of:** Von Mises	1.57584e-007 N/m^2	3.37598e+007 N/m^2



Note: The values of the Von Mises put are Constraint
Min: 1.57584e-007 N/m^2
Max: 3.37598e+007 N/m^22

Table 15: ABS Displacement 1500N

Name	Type	Min	Max
Displacement	**URES:** Displacement Resultant	0.118741 mm **Node:** 7412	30.5851 mm **Node:** 316



Note: The resulting displacement values are
Min Displacement: 0.118741 mm
Max Displacement: 30.5851 mm

Table 16: ABS Deformations 1500N

Name	Type	Min	Max
Deformations	**ESTRN:** Deformation Equivalent	4.60761e-017 **Item:** 18997	0.107492 **Item:** 7263

Note: The resulting deformation values are
Min Deformation: 4.60761e-017
Max Deformation: 0.107492

Table 17: ABS Deformations 1500N

Name	Type
Displacement	Distorted model

Modeled material is worthless displacement and deformation.

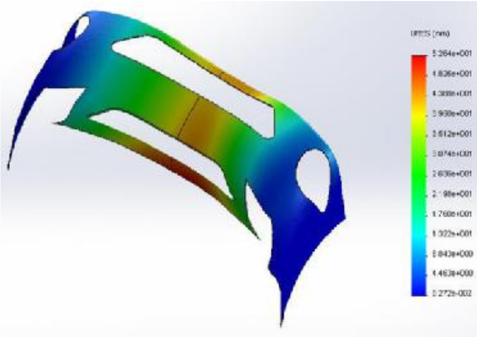
Table 18: Von Mises Constraint for ABS (3500)

Name	Type	Min	Max
Constraints	**Constraint of:** Von Mises	1.21748e-007 N/m^2 **Noeud:** 1328	5.65431e+007 N/m^2 **Noeud:** 6

Note: Von Mises stress values are Stress
Min: 1.21748e-007 N/m^2
Max: 5.65431e+007 N/m^2

Table 19: ABS Displacement 3500N

Name	Type	Min	Max
Displacements	URES: Displacement Resultant	0.08272mm **Node:** 5394	52.6418 mm **Node:** 306



Note: The resulting displacement values are
Min Displacement: 0.082724 mm
Max Displacement: 52.6418 mm

Table 20: ABS Deformations 3500N

Name	Type	Min	Max
Deformations	**ESTRN:** Deformation Equivalent	1.31433e-016 **Item:** 7111	0.194014 **Item:** 7263

Note: The resulting deformation values are:
Min Deformation 1.31433e-016
Max Deformation 0.194014

Table 21: ABS Deformations 3500N

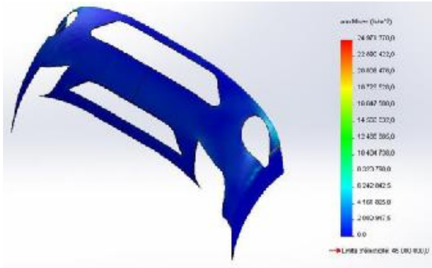
Name	Type
Deformations	Distorted model

Modeled material on displacement and deformation without values
The second material to choose Acrylic.

The Applied Force and 1000N

Table 22: Von Mises stress for Acrylic 1000N

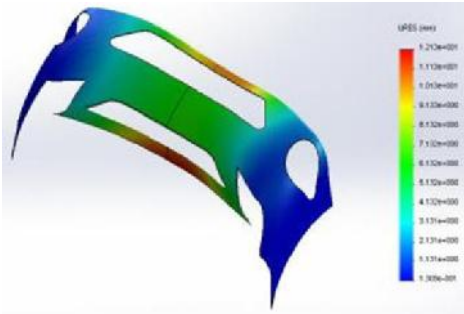
Name	Type	Min	Max
Constraints	**Constraint of:** Von Mises	0.0208499 N/m^2 **Node:** 3983	2.49714e+007 N/m^2 **Node:** 6



Note: The values of The constraint of Von Mises are Constraint
Min Constraint: 0.0208499 N/m^2
Max Constraint: 2.49714e+007 N/m^2

Table 23: Acrylic Displacement 1000N

Name	Tupe	Min	Max
Displacement	**URES:** Displacement resultant	0.130893 mm **Node:** 7455	12.1333 mm **Node:** 310



Note: The resulting displacement values are displacement
Min Displacement: 0.130893 mm
Max Displacement: 12.1333 mm

Table 24: Acrylic Deformations 1000N

Name	Type	Min	Max
Deformations	**ESTRN:** Deformation equivalent	1.24734e-011 **Item:** 15447	0.0495554 **Item:** 7263

Note: The resulting deformation values are:
Min Deformation: 1.24734e-011
Max Deformation: 0.0495554

Table 25: Acrylic Deformations 1000N

Name	Type
Deformations	Distorted model

Model material on displacement and deformation without value

The Applied Force and 1500 N

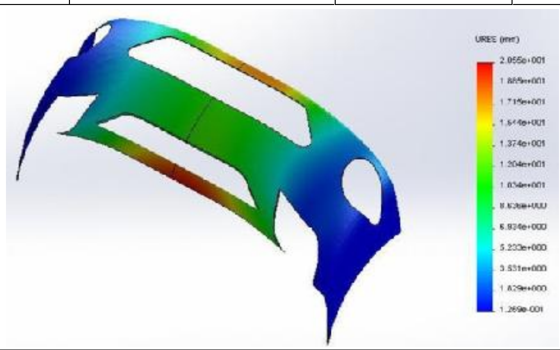
Table 26: Von Mises Constraints for Acrylic 1500N

Name	Type	Min	Max
Constraints	**Constraints of:** Von Mises	0.0208499 N/m^2 **Node:** 3983	2.49714e+007 N/m^2 **Node:** 6

Note: Von Mises stress values are constrained
Min: 0.0208499 N/m^2
Max: 2.49714e+007 N/m^2

Table 27: Acrylic Moves 1500N

Name	Type	Min	Max
Displacements	**URES:** Displacement resultant	0.126935 mm **Node:** 5396	20.5493 mm **Node:** 310



Note: The resulting displacement values are
Min Displacement: 0.126935 mm
Max Displacement: 20.5493 mm

Table 28: Acrylic Deformations 1500N

Name	Type	Min	Max
Deformations	**ESTRN:** Deformation equivalent	7.59668e-017 **Item:** 9965	0.0827896 **Item:** 7263

Note: The resulting deformation values are
Min Deformation: 7.59668e-017
Max Deformation: 0.0827896

Table 29: Acrylic Deformations 1000N

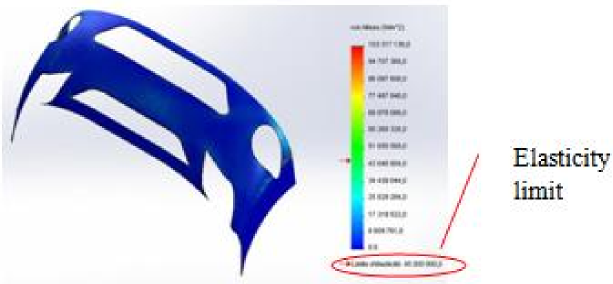
Name	Type
Deformations	Distorted model

Modeled material on displacement and deformation without value

Tge Applied Force and 3500N

Table 30: Constraints of Von Mises for Acrylic 3500N

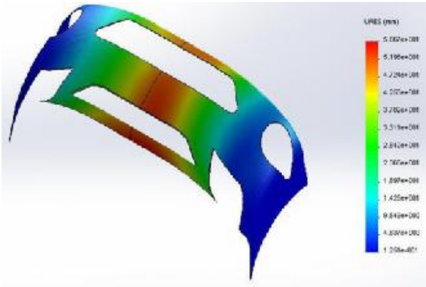
Name	Type	Min	Max
constraints	**Constraints of:** Von Mises	2.03451e-007 N/m^2 **Node:** 5182	1.03317e+008 N/m^2 **Node:** 920



Note: Von's stress values are Constraint
Min: 2.03451e-007 N/m^2
Max Stress: 1.03317e+008 N/m^2
Elasticity Limit: 4.5e-007 N/m^2

Table 31: Acrylic Displacement 3500N

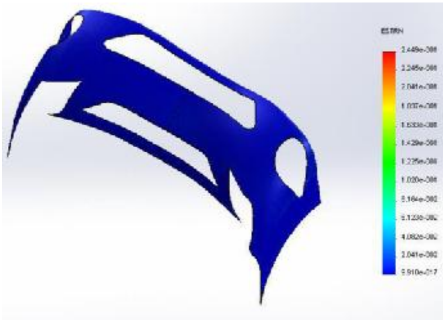
Name	Type	Min	Max
Displacements	**URES:** Displacement resultant	0.125125 mm **Node:** 5394	56.6678 mm **Node:** 306



Note: The resulting displacement values are
Min Displacement: 0.125125 mm
Max Displacement: 56.6678 mm

Table 32: Acrylic Deformations 3500N

Name	Type	Min	Max
Deformations	**ESTRN:** Deformation equivalent	9.90956e-017 **Item:** 18343	0.244909 **Item:** 7263



Note: The resulting deformation values are
Min Deformation: 9.90956e-017
Max Deformation: 0.244909

Table 33: Acrylic Deformations 3500N

Name	Type
Deformations	Distorted model

Modeled material on worthless displacement and deformation

RESULTS AND DISCUSSIONS

Let's make a summary after applying the different loads on the two materials by curves represented on the following Figures:

Figure 4 show the Von-Mises stress of the Acrylic material is low compared to that of the ABS material.

Figure 5 show the deformation of Acrylic material is high compared to ABS material.

Figure 6 show the displacement of the Acrylic material is higher than that of the ABS material.

According to the comparison of the results obtained in Von-Mises values, deformation and displacement, the material of construction of the impact is the ABS material which gave good results compared to the Acrylic material for the same boundary conditions.

Taking into account that the value of the applied load is 3500 N, beyond that a higher load cannot be applied.

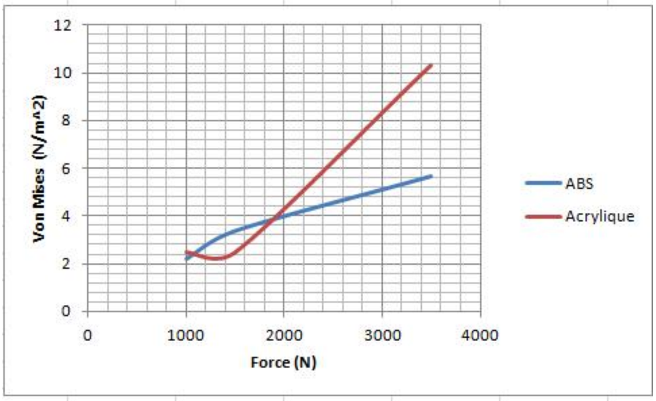


Figure 4: Evaluation of the Von-Mises Constraint Based on the Load.

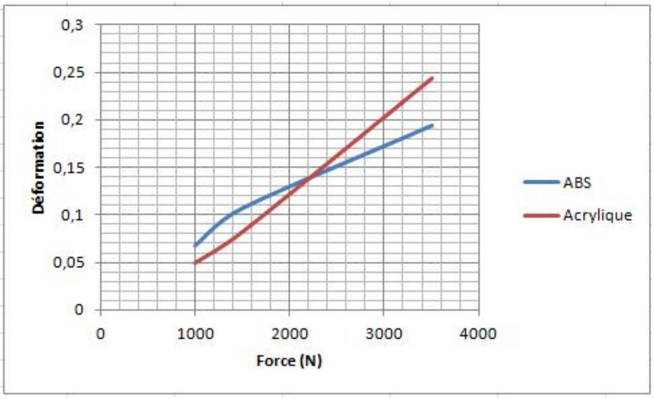


Figure 5: Evaluation of Deformation Based on Load.

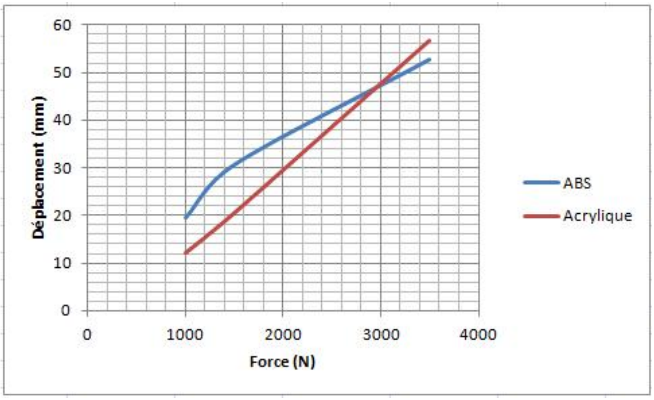


Figure 6: Assessing the Movement Based on the Load.

GENERAL CONCLUSIONS

This study allowed us to choose between two composite materials used for the construction of car bumpers. To achieve this objective, both materials ABS and Acrylic were solicited to a static rupture (impact test) starting with a load of 1000N, passing by the value of 1500N and ending with 3500N.

After CAD design, numerical simulation by SOLIDWORKS software and analysis of Von- Mises results, we can say that ABS (acrylonitrile butadiene styrene) material is the best used for this kind of automotive parts.

Hoping that this work helps car manufacturers to make the right choice of the bumper construction material which is an important element to the safety of people in the road

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