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STRENGTH ANALYSIS OF THE FRONT BUMPER BEAM OF A PASSENGER CAR

This article presents a computer simulation carried out in the Solidworks environment, the bumper beam of a passenger car was tested. The simulation took into account the influence of various aluminum alloys and the type of reinforcement in the cross-section of the beam on the strength of the entire element at the time of collision at different forces. The analysis provided answers in which places the accumulation of stresses occurs, and thus the places most exposed to destruction

Keywords: computer simulation; automotive; bumper beam; finite element method

1. Introduction

Computer simulation has its origins in the 1970s when it began to be used in the automotive and aerospace industries. Nowadays we are experiencing rapidly changing technology, which also has an impact on computer simulation, which is now used in every field of industry from those that people encounter on a daily basis such as the industry that manufactures telephones, cars and everyday things around us, as well as in the very advanced aviation, aerospace and military industries. Computer simulations make it possible to answer many questions just before the final production of a component. It is possible to choose the right material, the geometry of the component, add possible reinforcements [1-3]. Advanced computer simulations also make it possible to answer many questions such as whether a given structure can withstand a given load, determine the thermal properties of the model, determine the system's own vibrations, generated noise or determine the life of the model. Thanks to such solutions, companies are able to save on production time, which is reduced by producing the required structures for, such as strength tests, and already at the design stage determine many factors of the manufactured component. Thus, there is also an improvement in the economy of the company, which saves production materials and consumable machines and thus saves money [4-6].

Programs that allow you to perform these calculations belong to the group of CAE programs – Computer Aided Engineering. These programs use numerical methods, mainly the Finite Element Method, which is based on the discretization of the model into a finite number of elements connecting in nodes. The model is divided into very small elements, the quality of which, i.e. the size of the elements as well as the shape, depends on the computational capability of the computer. The quality of the finite elements mainly determines the results that are obtained from the simulation, also the correct execution of the discretization of the model allows to obtain the most accurate results, approximating reality [7-11] CAx programs are a group of computer-aided design programs and can be divided into smaller modules such as:

- CAE – Computer Aided Engineering
- CAD – Computer Aided Design,
- CAM – Computer Aided Manufacturing
- FEA – Finite Element Analysis
- CFD – Computional Fluid Dynamics
- MBD – Multibody Dynamics

Programs using FEA calculations can be divided according to the stages of work and thus the components of the programs from which they are built [12-17]:

- Preprocessor – is a program that allows you to determine the physical properties of the model such as shape, geometry, assign material. At this stage, the mesh of the model is also prepared, and boundary conditions are assigned to carry out the desired simulation,
- Processor – this system uses the computing power of the workstation to carry out the calculations defined in the preprocessor, the time to solve the calculations depends on

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the computing power as well as how complex the element is, i.e. the number of finite elements.
- Postprocessor – at this stage, the user has at his disposal tools related to reading the results as well as the way they are presented. It is also possible to import the results into other programs.

The rapid development of the automotive industry over the past decades is particularly evident in the improving technological solutions that upgrade travel comfort. However, it is not only driving comfort that is becoming better, factors that improve the safety of occupants inside the vehicle during a collision are also improving. Among the solutions improving this factor are the construction materials used, which mainly include [18-20]:
- ferrous metals – ultra-high-strength steel, high-strength steel,
- non-ferrous metals – aluminum, less commonly titanium,
- polymer composites,
- glass.

One of the solutions that really affect safety during an accident is the bumper beam, which is mounted behind the outer skin of the bumper (the outermost part of the car structure marked in green Fig. 1). The purpose of the bumper beam is to absorb the force of the impact resulting from a collision. As a result, it affects the safety as well as comfort of driving, the materials used in their production include structural aluminum alloys. The use of aluminum alloys is more and more common these days due to excellent properties such as [21-25]:
- high strength,
- much better corrosion resistance than steel,
- lower specific gravity than steel, which results in lower car weight making vehicles more environmentally friendly,
- good thermal conductivity and low thermal expansion.

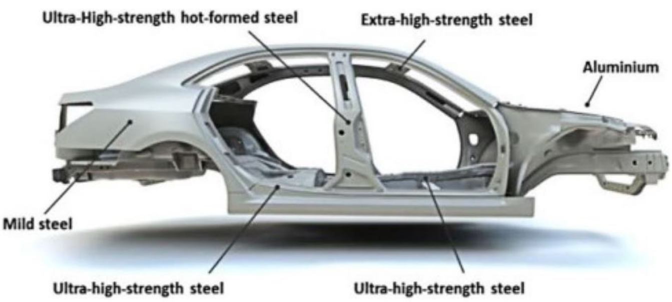

Fig. 1. Use of different materials for passenger car components [24]

2. Methods of research

Using the CAD program Solidworks, three types of beams with the same dimensions but with altered reinforcement were designed (Figs. 2-4). The next stage of the work was to create a mesh (Figs. 5-7). As can be seen, the number of elements increases, with model A having the fewest with 8318 elements, followed by model C with 10472 elements and model B having the most elements with 13307 elements. All meshes feature the same number of Jaciobian points – 16.

TABLE 1

Designed models for simulation

Model A	beam without reinforcement
Model B	beam with reinforcement in the form of X
Model C	beam with cross reinforcement

Then the boundary conditions of the simulation were defined, which included stationary fixation on two bases, an applied force along the entire length of the beam, so as to simulate an impact with a large obstacle (Figs. 8-9). The simulation assumed an impact force of 125,000 [N]. The next step of the study was to define the material, it was decided to assign aluminum alloy 6063 – T6, it is a heat-treated and naturally aged aluminum alloy. The properties of the alloy are shown in TABLE 1, while the chemical composition of the 6063 alloy is shown in TABLE 2.

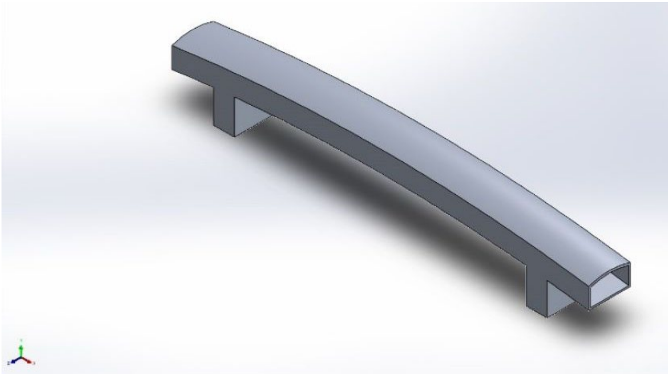

Fig. 2. Bumper beam without main profile reinforcement – model A

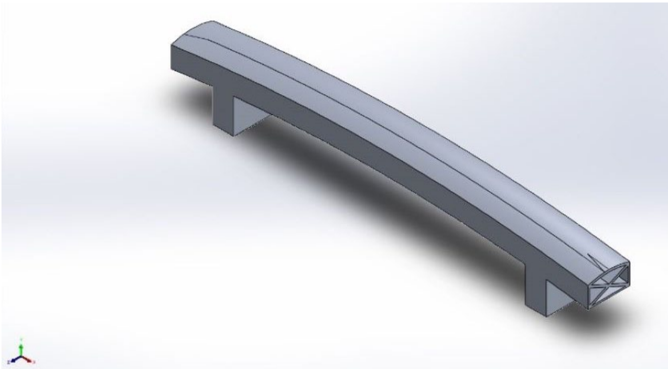

Fig. 3. Bumper beam with main profile reinforcement – model B

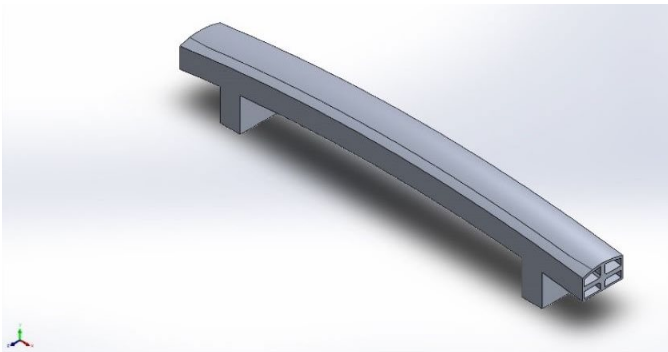

Fig. 4. Bumper beam with main profile reinforcement – model C

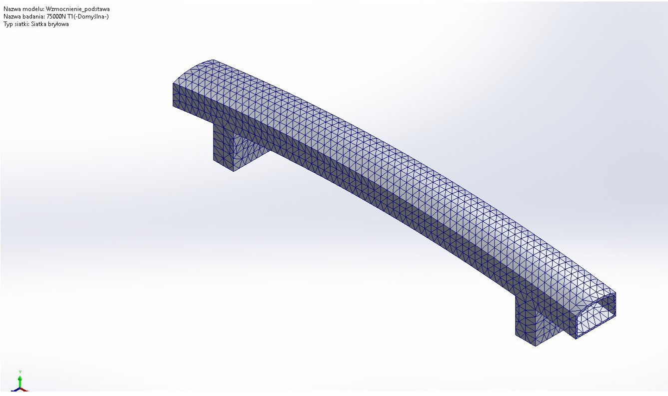

Fig. 5. Model A with applied mesh

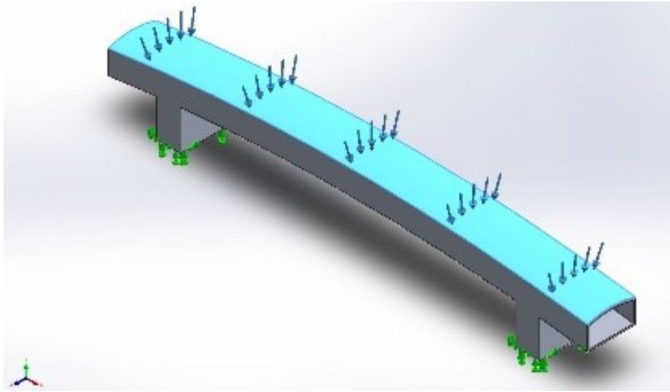

Fig. 9. Model fixing points indicated in green

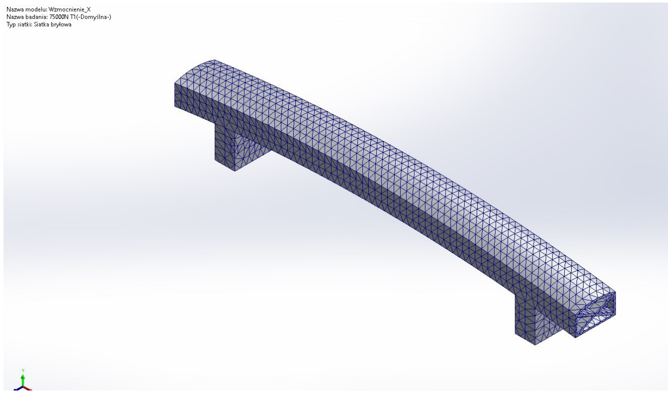

Fig. 6. Model B with applied mesh

TABLE 2

Properties of the 6063-T6 aluminium alloy
from SolidWorks database

Property	Value	Unit
Elasticity coefficient	6.9e+10	N/m^2
Poisson's ratio	0.33	n.d.
Shear stress coefficient	2.58e+10	N/m^2
Specific mass	2700	kg/m^3
Tensile strength	240000000	N/m^2
Yield strength	215000000	N/m^2
Coefficient of thermal expansion	2.34e-05	/K
Coefficient of thermal conductivity	209	W/(m·K)
Specific heat	900	J/(kg·K)

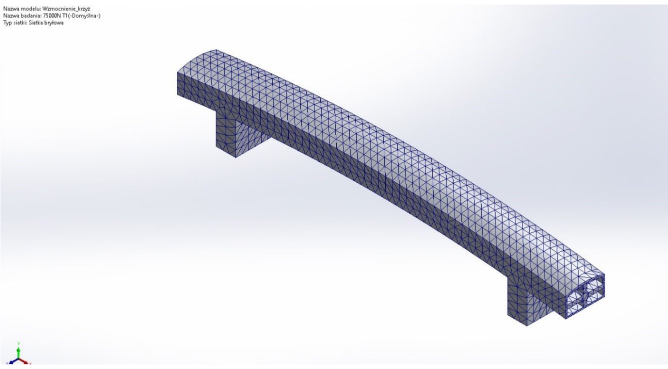

Fig. 7. Model C with applied mesh

TABLE 3

Chemical composition of aluminium alloy 6063 [6]

Alloy	Si [%]	Fe [%]	Cu [%]	Mn [%]	Mg [%]	Cr [%]	Zn [%]	Ti [%]
6063	0,2-0,6	0,35	0,1	0,1	0,45-0,9	0.05	0,1	0,1

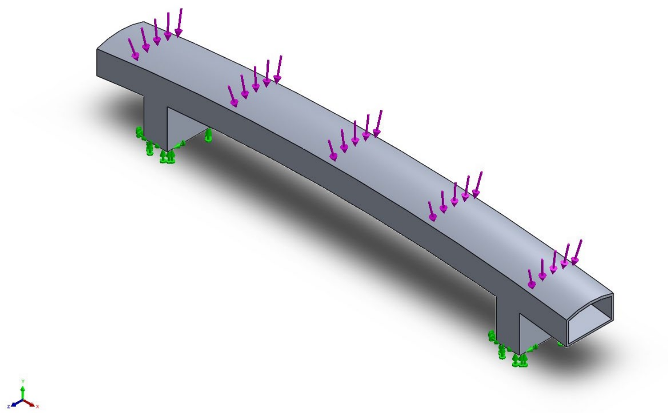

Fig. 8. Place of force application

3. Course of the study

Using the boundary conditions mentioned in the paper above, simulations were run for each modeled beam, considering the same material and applied force, resulting in three simulations. The results obtained from the simulations are shown in Figs. 10-18, all results proved that in each model the accumulation of deformation and stresses occurs in the central part of the model. These results show the strength of the models to frontal impact over the entire beam surface with a force of 125,000 [N] using the same aluminium alloy, which was 6063-T6 alloy, but the beams were characterised by different reinforcement geometries. Model A without reinforcement has, as expected, the worst strength properties and the highest displacement, but the lowest weight. Model B, with an X-shaped reinforcement, is in the middle in terms of performance, while model C, with a cross-shaped reinforcement, has the best strength properties and the highest weight. Figs. 10, 13, 16, show the stress diagrams of the simulated beams, Fig. 10 for a beam without reinforcement, Fig. 13 for a beam with X-shaped reinforcement and Fig. 16 with

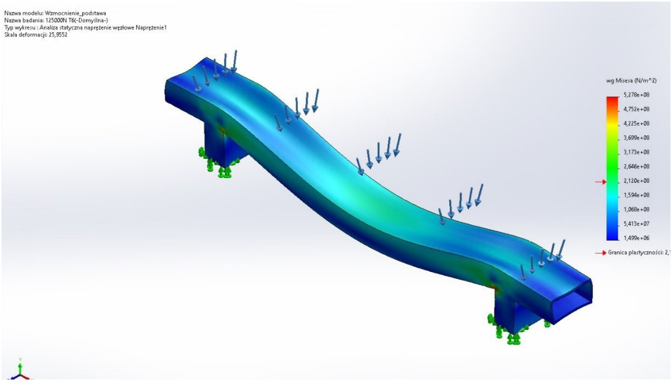

Fig. 10. Stress result of model A at a force of 125000 [N] for alloy T6

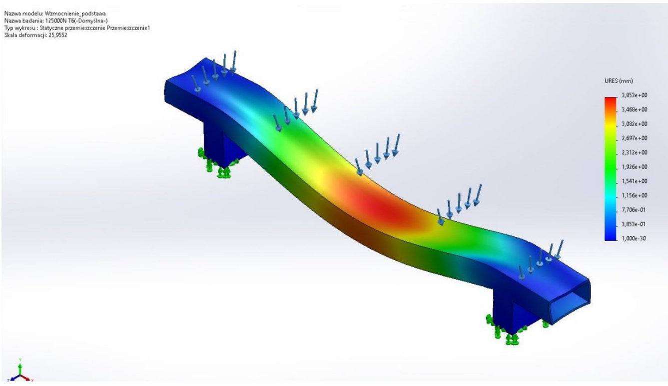

Fig. 11. Displacement result of model A at a force of 125000 [N] for alloy T6

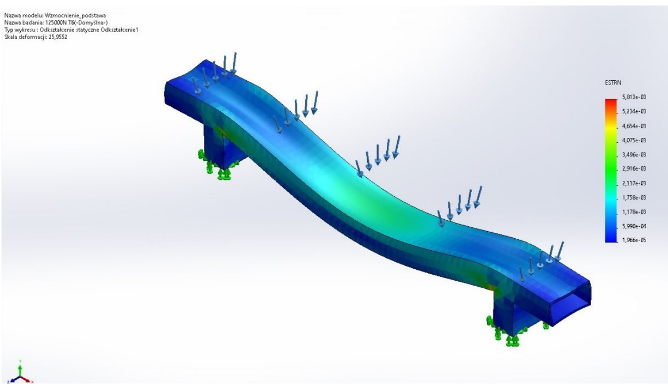

Fig. 12. Deformation result of model A at a force of 125000 [N] for alloy T6

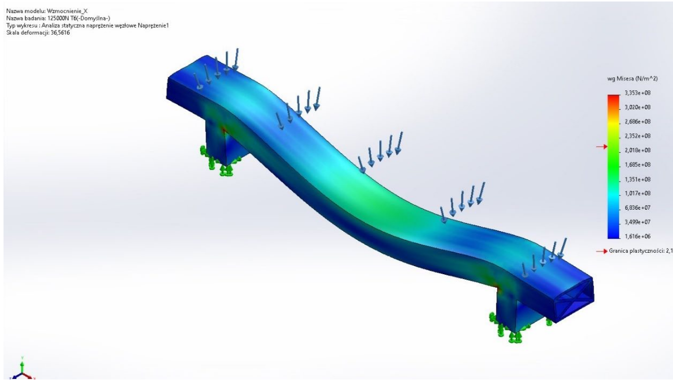

Fig. 13. Stress result of model B at a force of 125000 [N] for alloy T6

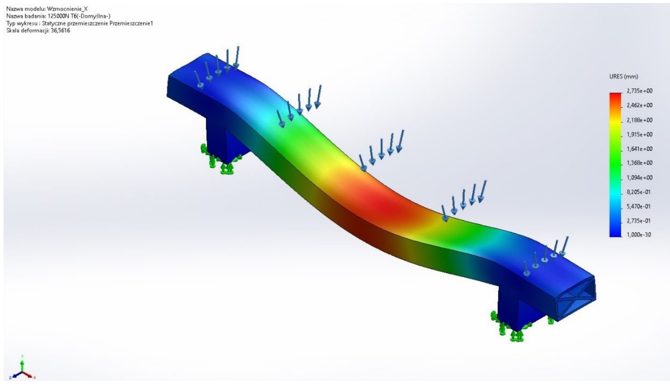

Fig. 14. Displacement result of model B at a force of 125000 [N] for alloy T6

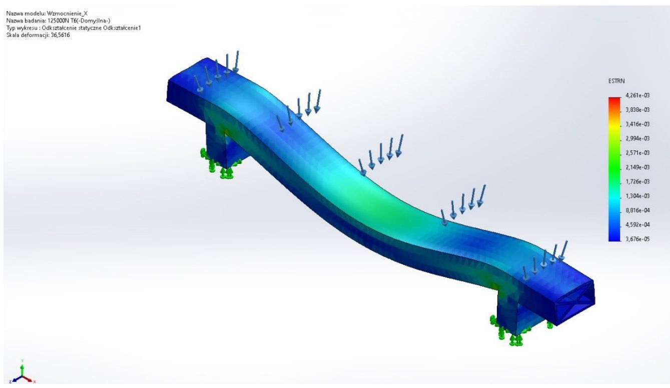

Fig. 15. Deformation result of model B at a force of 125000 [N] for alloy T6

cross-shaped reinforcement. The next graphs (Figs. 11, 14, 17) show the results of the displacements, which have their accumulation at the centre of the beams. The last diagrams (Figs. 12, 15, 18) show the results of deformations. The bases of the beam joints to the rest of the car structure were not affected in any of the three beams, which is evidence of well-modelled beams.

4. Conclusions

The results of the simulations are summarized in TABLE 3, where the maximum stresses and displacements of specific models after applying a force of 125,000 [N] are shown. The results provided showed that the main area exposed to damage and stress accumulation is in the central part of the beams. It was found after computer simulation that the results of stress and displacement indicate that model C (beam with cross-shaped reinforcement) obtained the best results, the lowest stress value of 234 [MPa] was recorded, which indicates that the model is capable of carrying more stress than the other models, and the lowest displacement of 2.20 [mm]. The worst result as could be assumed in advance turned out to be the model without any reinforcement where the highest stress and displacement results were observed: 528 [MPa] and 3.85 [mm]. The yield strength

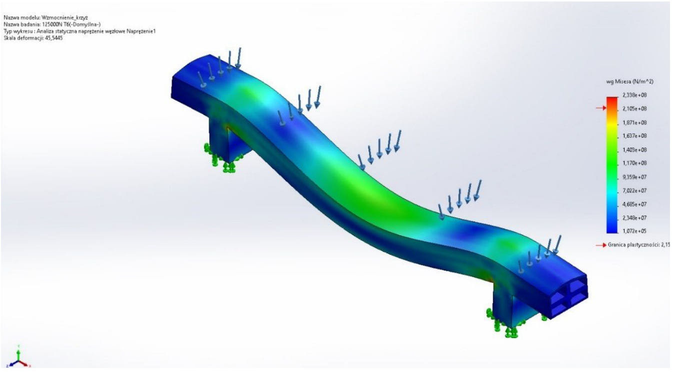

Fig. 16. Stress result of model C at a force of 125000 [N] for alloy T6

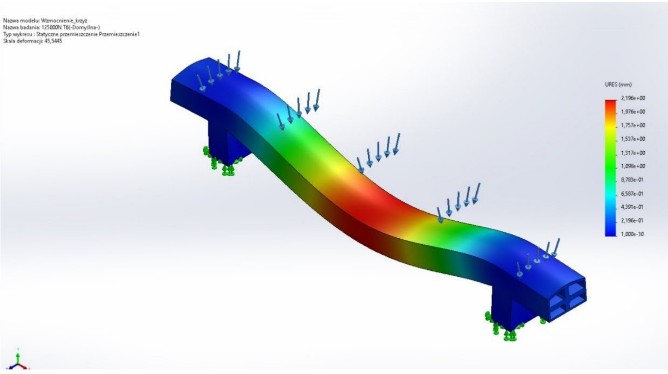

Fig. 17. Displacement result of model C at a force of 125000 [N] for alloy T6

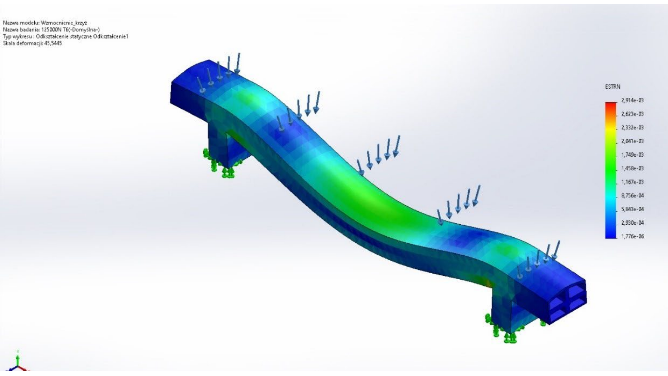

Fig. 18. Deformation result of model C at a force of 125000 [N] for alloy T6

(215 [MPa]) was exceeded in every model, only model C was characterized by a similar value, and the difference was only 19 [MPa]. The results showed that the geometry of the reinforcement has a real effect on the impact resistance of the beam. It can therefore be concluded that choosing the right geometry for the bumper beam is very important for the safety of car users. Choosing the right geometry for the beam is also important in terms of weight, which is a very important aspect in the automotive industry, because using a better and larger cross-section of beam reinforcement will result in increased safety, but it will increase the weight dramatically and thus increase the fuel consumption of the vehicle.

TABLE 4

Stress and displacement result

Model	Tension [MPa]	Displacement [mm]
A	528	3,85
B	335	2,74
C	234	2,20

Results:

- the geometry of the beam reinforcement affects its strength,
- the best reinforcement among the selected ones is the cross reinforcement (model C),
- the analysis made it possible to find the places where the highest stresses accumulate,
- the largest displacements were observed in the middle part of the beam,
- the yield strength of the material was exceeded in each model

Present some future implications and further works considerations resulting from the presented results. Computer-aided engineering technology has certainly been developing for a good few decades now and it continues to evolve. Through the use of CAE, it is possible to study not only static stress distributions or displacements. Increasingly, CAE is being used to simulate crash tests of entire cars, investigate the noise generated by various mechanisms and much more. In the future, this technology allows, as an example of this article, the best shape and geometry of a beam to be selected, as well as the right material to provide the best desired properties.

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