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Analysis and simulation of impact tests on automotive elements using two types of high-strength steels

Análisis y simulación de prueba de impacto en elementos automotrices utilizando dos tipos de aceros de alta resistencia

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Abstract

This research, the main objective is to study and analyze the behavior of the automobile part called front bumper reinforcement, subjected to impact; For this, two types of materials belonging to the family of ultra-high strength steels will be used, since they are two materials that have excellent mechanical properties. To carry out the studies, a simplified model of said piece was increased; likewise, the analyzes will be developed with the help of CAE software. To carry out the process, a series of stages will be developed, ranging from the development of the model to be analyzed, considering its geometric study characteristics, as well as the knowledge of the mechanical properties of the materials to be worked on. In the same way, the conditions to which the element is subjected at the moment of impact will be known and applied. The force applied to the element will be subject to the speeds according to the standards used for this type of parts in impact tests. This research contributes to the studies of parts that are part of the safety of the vehicle, as well as knowing the mechanical advantages that 38MnB5 steel has compared to 22MnB5 steel.

Properties, Conditions, Analysis

Resumen

Esta investigación tiene como principal objetivo estudiar y analizar el comportamiento que tiene la pieza del automóvil denominada refuerzo de parachoques frontal, sometida a impacto; para lo anterior se utilizarán dos tipos de materiales pertenecientes a la familia de aceros de ultra alta resistencia, debido a que son dos materiales que poseen excelentes propiedades mecánicas. Para realizar los estudios se utilizará un modelo simplificado de dicha pieza; así mismo, los análisis se desarrollarán con la ayuda de un software CAE. Para llevar a cabo el estudio se desarrollarán una serie de etapas las cuales van desde el desarrollo del modelo a analizar, considerando sus características geométricas, así como el conocimiento de las propiedades mecánicas de los materiales a trabajar. Del mismo modo, se conocerá y aplicarán las condiciones a las que está sometido el elemento al momento del impacto. La fuerza aplicada al elemento estará sujeta a la o las velocidades de acuerdo con las normas utilizadas para a este tipo de piezas en pruebas de impacto. Esta investigación contribuye a los estudios de piezas que forman parte de la seguridad del vehículo, así como el conocer las ventajas mecánicas que tiene el acero 38MnB5 respecto al acero 22MnB5.

Propiedades, Condiciones, Análisis

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Introduction

The vehicle is a system that has been improving in terms of safety. The study of new materials makes it possible that the structural elements that make up the car are getting better and better and favor its efficiency.

Studying the behavior of new materials that are related to the elements that make up the chassis and body of the vehicle is of utmost importance, because today it is necessary to have a car that consumes little fuel without neglecting the safety of the driver. Vehicles are exposed to various types of incidents, among the most risky are: frontal impacts, side impacts and rollovers.

The proper use of CAD and CAE software facilitates the study and analysis of the elements to be examined, making the pertinent considerations in order to obtain results that are as close to reality as possible. The finite element analysis is of utmost importance, since it is a method that allows calculating and visualizing the stresses and deformations to which an element subjected to external loads is subjected.

The objective of this analysis is to determine the stresses and deformations of the front bumper reinforcement, which will be subjected to a frontal impact. The element will be analyzed using two types of materials, both 22MnB5 steel and 38MnB5 steel. This study will make it possible to make a balance on both materials and with it deduce the best option for the structural elements in question.

In the process of this writing, the methodology that was worked in order to find the expected answer will be observed. Likewise, the development carried out within the work is found, where the investigation of the mechanical properties of each of the materials to be studied is found, as well as the development of the models with the help of a CAD software; on the other hand, the selection of speeds at which the impacts can occur is considered, that is to say, it is intended to review the speeds that by norm are established in terms of impacts, likewise, other speeds at which the element can fracture will be analyzed; with the above and finally the conditions can be simulated with the support of a CAE software.

Methodology

In order to achieve the expected objectives, a series of specific steps were carried out, these are presented in the methodology shown in Figure 1, in which the elements to be analyzed, the materials to be used and the type of finite element analysis to be performed were defined in general.

The elements proposed in the methodology were considered adequate and precise to carry out the research in a planned and organized manner.

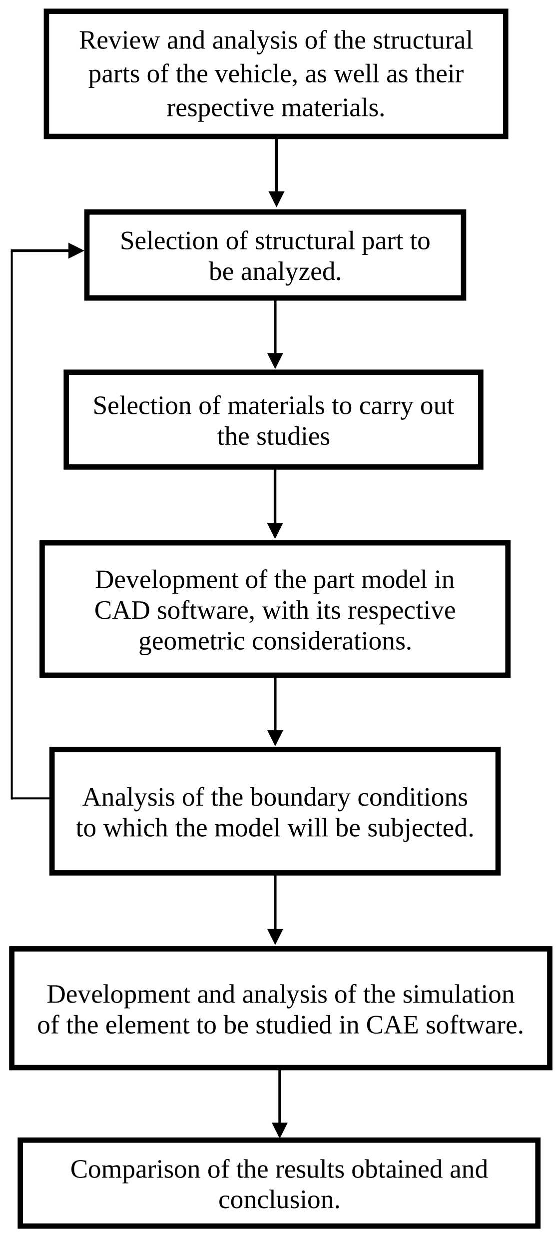

Figure 1 Methodology
Source: Own elaboration

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Development

Pieces selected for the study

The elements that are part of the vehicle body are developed in such a way as to provide rigidity, while at the same time being able to absorb energy in the event of an impact.

Inside the vehicle there are parts that are of utmost importance at the time of performing a safety study. In this work the analysis focused on the front bumper reinforcement.

The main purpose of the front bumper is to protect passengers from a frontal impact in the event of any collision.

Figure 2 shows the different parts of the car body, including the front bumper reinforcement.

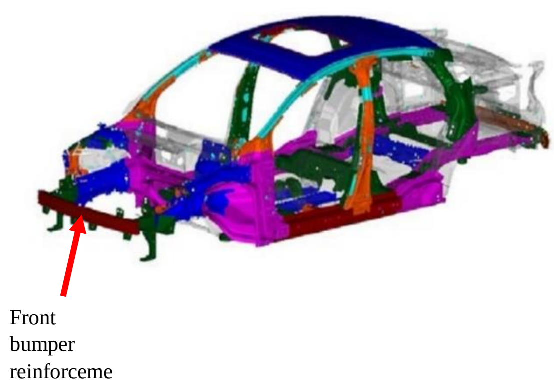

Figure 2 Automobile body parts.
Modified: Cora, Ö. & Koç, M., 2014"

Materials used for the study

Nowadays, different materials are used in the design of the vehicle chassis; these materials have the objective of resisting high impacts, damaging the users as little as possible, in such a way that they are capable of absorbing a large amount of energy.

To carry out the study, 2 materials were selected, which were 22MnB5 steel and 38MnB5 steel. The aforementioned materials were taken into account for the study, due to their common use in the structural parts of the vehicle, that is, these materials are the ones that can be used in the elements that will be worked on in this document.

Prior to the development of the study and knowing the materials to be used, the chemical compositions of each material were investigated. Table 1 shows the components of both 22MnB5 and 38MnB5 steel (in %), where it is possible to observe that they have the same elements.

Component	22MnB5	38MnB5
C	0.225	0.380
Si	0.211	0.190
Mn	1.229	1.200
P	0.018	0.015
S	0.008	0.004
Cr	0.289	0.280
Mo	0.001	0.005
Ni	0.000	0.005
B	0.0041	0.0030
N	0.0049	0.0047
T	0.037	0.024

Table 1 Chemical composition of 22MnB5 and 38MnB8/5 steels
Source: Data obtained: Taylor, T. et al., 2014

On the other hand, in order to know the behavior of the material, the mechanical properties of the material were analyzed, which are shown in Table 2. These properties were necessary since, for the finite element study, it is necessary to characterize the material, taking into account some properties, among them those shown in Table 2.

Test	Feature	Material	
		22MnB5	38MnB5
Voltage	$R_{p0.2}$ (MPa)	1066 ± 7	1390 ± 107
	R_m (MPa)	1463 ± 18	2049 ± 0
	$A_u(\%)$	3.6 ± 0.1	3.4 ± 0.0
	A_{50} $(\%)$	8.1 ± 0.1	3.4 ± 0.0
Hardness	$HV10$ $(kg\ mm^2)$	476	651
	SD $(kg\ mm^2$	1.6	12.5
Microstructure	$Ferrita$ $(vol.\%)$	0.0	0.0
	$Martensita$ $(vol.\%)$	100	100
	$Ferrita$ (µm	N/A	N/A

Table 2 Mechanical properties of 22MnB5 and 38MnB8/5 steels
Source: Data obtained: Taylor, T. et al., 2014"

Both 22MnB5 and 38MnB5 are materials belonging to the ultra high strength steels (UHSS) family. This type of material is characterized by its high tensile strength, while at the same time it has thin sheet thicknesses, ranging from 1 mm to 2 mm. The aforementioned characteristics help to make the vehicle lighter without losing impact resistance.

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CAD model development

A necessary tool for the visualization of structural elements (in general), is the use of software, since they save time and tend to be very accurate.

The model to be studied was made within a CAD software for its subsequent simulation. To carry out the analysis, a simplified model of the front bumper reinforcement was developed, in which the most important geometrical characteristics of these parts were considered.

To carry out the model of the part, a thickness of 1.4 mm was estimated, which is one of the most used thicknesses in practice. Figure 3 shows the idealized model of the element to be studied, in which the basic characteristics of the element were considered.

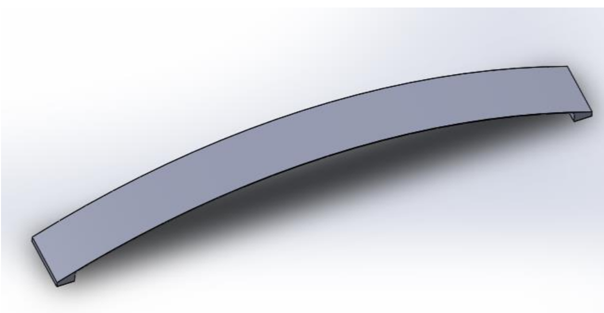

Figure 3 Idealized model of the front bumper reinforcement
Source: Own elaboration

Analysis and development of models in CAE

Like the CAD software, the CAE software allows, in addition to saving time, an economic saving, since different analyses can be performed, which allow the feasibility in the fabrication of elements.

An important point to highlight in the application of loads was the forces that would be applied to the model, since the feasibility of the material depends to a large extent on these.

Nowadays, there are organizations in charge of performing impact tests on vehicles in order to perform an analysis similar to a real accident and thus be able to determine with great accuracy the impact forces to which a vehicle is subjected at the time of the crash.

According to the Insurance Institute for Highway Safety "IIHS" (Insurance Institute for Highwey Safety), there is a frontal impact test at low speeds, in which the vehicle must have a speed of 10 km/h (Sonawane, C.R. & Shelar, A.L., 2018).

To conduct the study, the mass of the vehicle to be impacted was considered to have a mass of 1250 kg, which is a sedan type vehicle (Reichert, R. et al., 2018).

To determine the impact force, the definition of impulse and quantity of motion was used, which relates force, time and velocity, such definition is described by Equation 1 (Beer, F. et al., 2017):

$$\int_{t_1}^{t_2} F\,dt = mv_2 - mv_1 \quad (1)$$

Evaluating from t_1 to t_2 and clearing, one has Equation 2 (Beer, F. et al., 2017):

$$mv_1 + \Sigma F\,\Delta t = mv_2 \quad (2)$$

To determine the impact force acting on the vehicle, an impact time of 0.1s was considered. Table 3 shows the values of the forces according to the indicated speed. Initially, a speed of 10 km/h was considered, which is the speed indicated by the IIHS. Subsequently, it was considered to work with other speeds, with the purpose of observing how much force the element is able to withstand according to the material (22MnB5 and 38MnB5).

Speed	Impact force
10 km/h	34750 N
20 km/h	69500N
30 km/h	104125 N
32 km/h	111250 N
40 km/h	138889 N
42 km/h	145833 N

Table 3 Impact forces with respect to velocity
Source: Own elaboration

Prior to the finite element analysis, the conditions to which the element is subjected at the moment of impact were considered.

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These conditions are shown in Figure 4, in which the load (arrows in purple) and the fastening (arrows in green) were placed; this last condition, it was considered that there was no rotation and translation, because the part is attached to the body part of the vehicle by welding.

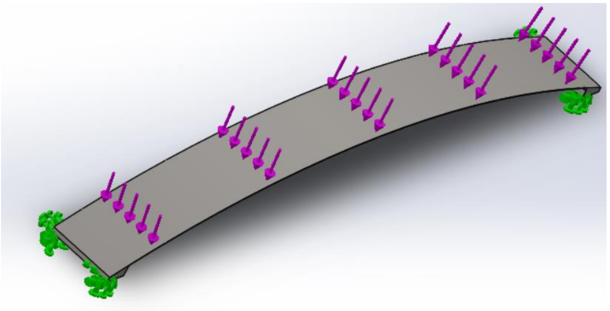

Figure 4 Loading and fastening conditions
Source: Own elaboration

Results

Due to the expected results, when performing the finite element analysis, the safety factor reached by the element exposed to the vehicle impact speed was considered.

Figure 5 shows the safety factor of the element, considering a speed of 10 km/h and the material 22MnB5; it can be seen that the element is capable of resisting such speed, since it has a 3.221 safety factor.

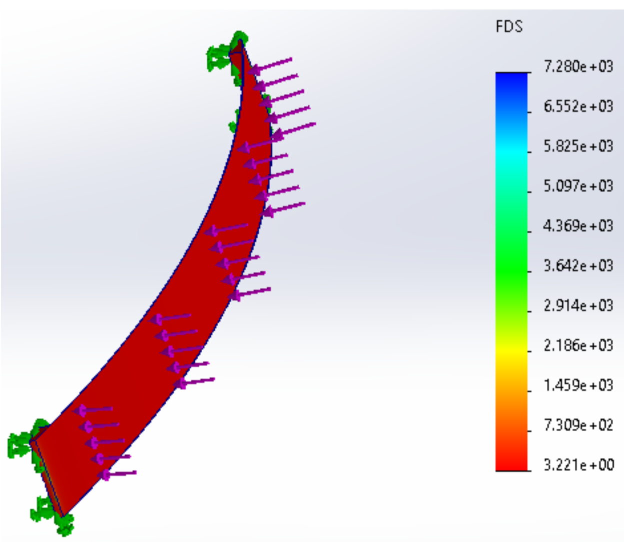

Figure 5 Element factor of safety, using 22MnB5 steel with impact velocity of 10 km/h
Source: Own elaboration

The analyses were carried out for speeds of 20 km/h, 30 km/h, until a speed of 32 km/h was obtained; at this last speed the element has a safety factor of 1, as shown in Figure 6.

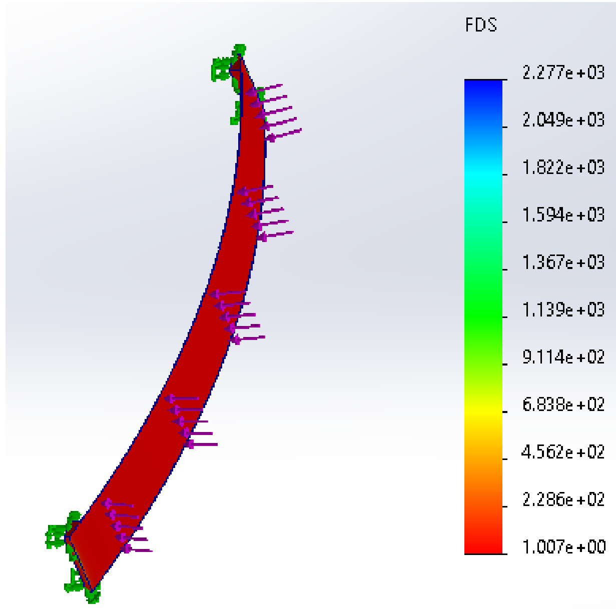

Figure 6 Element factor of safety, using 22MnB5 steel with impact velocity of 32 km/h
Source: Own elaboration

On the other hand, a similar study was carried out on the same element, using 38MnB5 steel. Considering an impact velocity of 10 km/h, it can be seen in Figure 7 that the element presents a safety factor of 4.199.

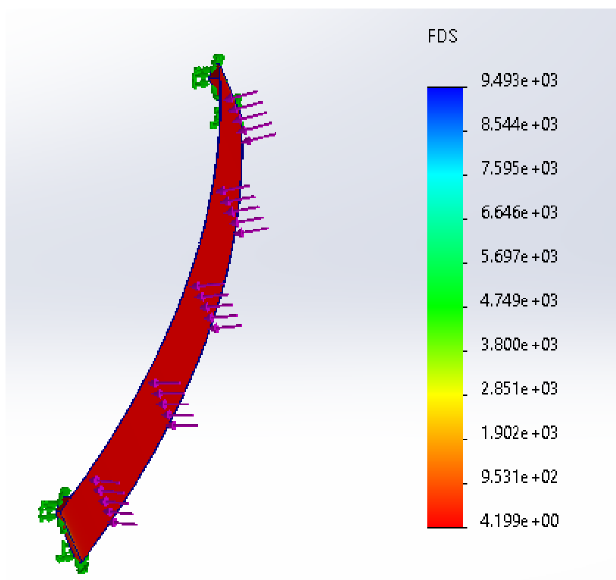

Figure 7 Element factor of safety, using 38MnB5 steel with impact velocity of 10 km/h
Source: Own elaboration

Similarly, studies were carried out for speeds of 20 km/h, 30 km/h, 40 km/h up to 42 km/h, where it was found that their safety factor was practically 1, as shown in Figure 8.

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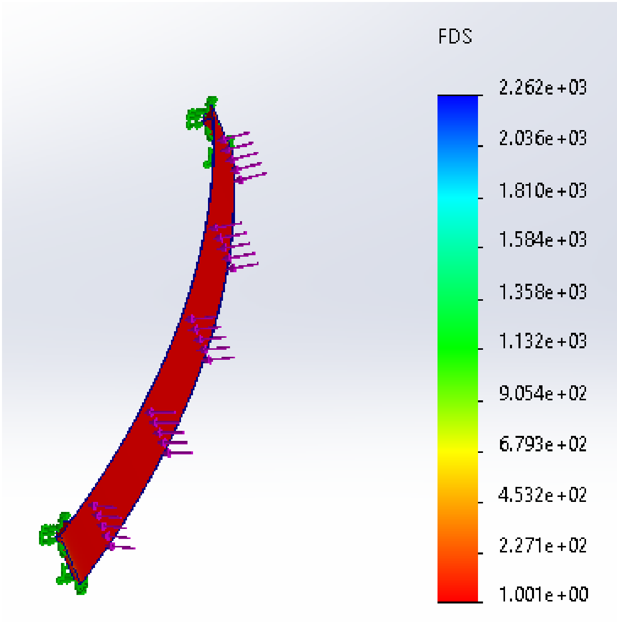

Figure 8 Element factor of safety, using 38MnB5 steel with impact velocity of 42 km/h
Source: Own elaboration

Table 4 shows a summary of the safety factor obtained with respect to impact velocity and material.

Velocidad de impacto	Material	Factor de seguridad
10 km/h	$22MnB5$	3.221
	$38MnB5$	4.199
20 km/h	$22MnB5$	1.61
	$38MnB5$	2.1
30 km/h	$22MnB5$	1.075
	$38MnB5$	1.401
32 km/h	$22MnB5$	1.007
	$38MnB5$	1.312
40 km/h	$22MnB5$	0.8058
	$38MnB5$	1.051
42 km/h	$22MnB5$	0.7674
	$38MnB5$	1.001

Table 4 Factor of safety with respect to impact velocity and material
Source: Own elaboration

To better visualize the results obtained, Figure 9 shows the graphical behavior of each of the materials.

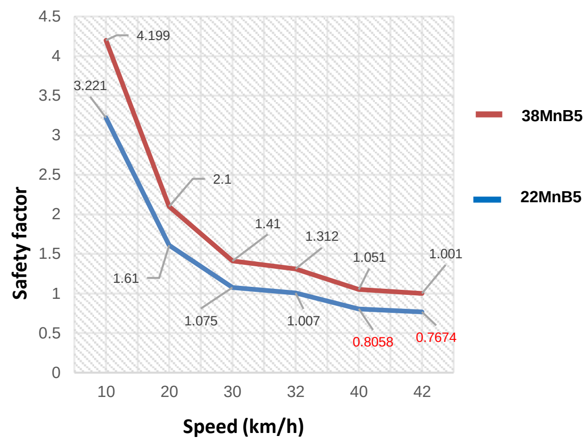

Figure 9 Graphical behavior of 22MnB5 and 38MnB5 materials
Source: Own elaboration

Conclusions

It was possible to represent, analyze and study the behavior of the front bumper reinforcement, subjected to the impact force caused by a speed of 10km/h (speed considered by the IIHS test).

The 38MnB5 material increases safety in a frontal impact by up to 23.29%, considering the test conditions.

Research and development of new materials leads to more efficient and safer vehicles.

General considerations

For confidentiality reasons, the model of the front bumper reinforcement had to be modified in terms of geometry and dimensions, but the most important characteristics had to be maintained. The average mass of a conventional vehicle was also taken.

Thank you

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