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Analysis and dynamic simulation of the cardan shaft for the minilow prototype vehicle

Análisis y simulación dinámica del eje cardán para vehículo prototipo mini baja

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Abstract

This article shows the finite element analysis for the simulation of dynamic loads to two prototype models of cardan shafts considering two types of material, alloy steel and 1045 steel, to determine the structural efficiency of work, by means of contour conditions extracted from two types of engines raised for a minilow vehicle. In order to perform the structural simulation of dynamic loads, it was essential to simulate motion analysis and determine that both models do not present some gap or energy irregularity. This consisted in obtaining the dynamic results (displacement and angular speed, torque and power), comparing them with those indicated by the manufacturer of each engine. The finite element analysis was then performed for the structural simulation of dynamic loads, identifying the element that generates the minimum Von Mises forces, the lowest unit displacement and the minimum safety factor. The aim of this work is to confirm whether the two models comply with the structural analysis of dynamic loads and, based on this, to select the one with the most favorable results to work on the transmission of a minilow car.

Analysis, Dynamic, Structural, Simulation, Efficiency

Resumen

El presente artículo muestra el análisis de elemento finito para la simulación de cargas dinámicas a dos modelos prototipo de ejes cardán considerando dos tipos de material, acero aleado y acero 1045, para determinar la eficiencia estructural de trabajo, mediante condiciones de contorno extraídas de dos tipos de motores planteados para un vehículo minibaja. Para realizar la simulación estructural de cargas dinámicas, fue imprescindible simular análisis de movimiento y determinar que ambos modelos no presenten algún desfase o irregularidad energética, lo cual consistió en obtener los resultados dinámicos (desplazamiento y velocidad angular, torque y potencia), comparándolos con los indicados por el fabricante de cada motor. Posteriormente se realizó el análisis de elemento finito para la simulación estructural de cargas dinámicas, identificando el elemento que genere los mínimos esfuerzos de Von Mises, el menor desplazamiento unitario y el mínimo factor de seguridad. En este trabajo se tiene como objetivo corroborar si los dos modelos cumplen con el análisis estructural de cargas dinámicas y en base a ello seleccionar el que comprenda con los resultados más favorables para trabajar en la transmisión de un auto minibaja.

Análisis, Dinámico, Estructural, Simulación, Eficiencia

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Introduction

BAJA SAE is an event for undergraduate engineering students, organised by the Society of Automotive Engineers. The event organised on behalf of the MiniBAJA competition serves as a platform for young engineering students to showcase their skills by designing, manufacturing and validating a single-seater off-road vehicle and gain real-life experience while overcoming obstacles and challenges. (HUERTA-GAMEZ *et al*., 2020).

The automotive drivetrain system is designed to handle the power generated by an internal combustion engine and deliver it directly to the rear wheels for rear-wheel drive vehicles. One of the most important mechanical elements that assists the transmission of power, torque and speed is the cardan shaft, which generally comprises a drive shaft, as well as crossheads and flanges that help to optimise the transfer of these mechanical forces, to name the most prominent ones (Ciornei *et al*., 2019).

The cardan shaft is the main element to transmit the engine power, therefore, the study of two models of cardan shaft for a minibox vehicle will be carried out. This analysis will be developed based on a structural simulation of motion loads with materials added to the models, such as alloy steel and 1045 steel and with two different types of selected engines, which will provide results for interpretation in dynamic and finite element structural analysis plots.

Motors used

The cardan shafts will be subjected to the simulation study by means of two motors, simulating the work, power and angular velocity they provide, observing the behaviour of the proposed shaft models.

The engines were selected under the criteria of the SAE regulation 2022 formula, which indicates that they must be four-stroke and less than or equal to 710 cc per cycle. The first engine selected is the Blue Core 4-stroke, forced air-cooled SOHC single-cylinder engine and the second is the CBF125 twister 4-stroke, SOHC 2-valve single-cylinder engine; the characteristics of both engines are shown in Table 1.

Technical specifications		
Engine	Blue Core	CBF125 TWISTER 2022
	4-stroke	4-stroke
	Single-cylinder	Single-cylinder
	SOHC	SOHC
	2-valve	2-valve
Maximum Power	11.9 Hp at 7500 RPM	8.5 Hp at 7000 rpm
Maximum Torque	12.8 N-m at 4500 RPM	10.1 N-m at 5000 rpm
Displacement	149 cc	124.7 cc
Transmission	5-speed return type	4-speed return type
Cooling System	Forced air	Forced air

Table 1 Engine characteristics
Source: Own Elaboration (Word)

Material used

The selection of the appropriate material is an important point to consider, as the results of the simulation will depend on it. Table 2 shows the materials used in the simulation, which are adjusted to the boundary conditions to which the cardan shaft will be subjected, such as power and torsion according to the analysis of the movement in the structural element.

Material	Alloy Steel	AISI-1045 steel	Symbol
Property	Value	Value	Units
Modulus of elasticity	210000	205000	N/mm^2
Poisson's ratio	0.28	0.29	N/D
Shear modulus	79000	80000	N/mm^2
Bulk density	7700	7850	kg/m^3
Tensile limit	723.8256	625	N/mm^2
Elastic limit	620.422	530	N/mm^2
Coefficient of thermal expansion	1.30E-05	1.15E-05	/K
Thermal conductivity	50	49.8	W/(m·K)
Specific heat	460	486	J/(kg·K)

Table 2 Mechanical properties of steels
Source: Own Elaboration (Word)

Two steel type materials were selected, alloy steel, due to its high carbon content and 1045 steel, the latter contains a lower percentage of carbon, however, it is frequently used for gear systems, bolts, transmission shafts, among other uses of high structural grade.

Figure 1 shows the parameters of the automotive cardan shaft. The basic length is 932 mm, while the outer diameter is 80 mm, and the inner diameter is 60 mm.

Figure 1 Geometric properties of the automotive cardan shaft
Source: Own Elaboration (Solidworks)

Figure 2 shows the parameters of the cardan shaft for a motor trolley. The basic length is 770.23 mm, while the outer diameter is 85 mm, and the inner diameter is 70 mm.

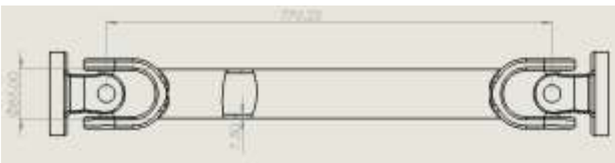

Figure 2 Geometrical properties of the trolley motor drive shaft
Source: Own Elaboration (Solidworks)

Analysis

After selecting the two engines, the Blue Core and the CBF125 Twister 2022, as well as the two types of drive shafts, the axles will be dynamically and structurally tested in order to be able to transmit power, speed and torque to the differential. The axles will be dynamically and structurally tested in order to be able to transmit power, speed and torque to the differential. Figure 3 shows the automotive driveshaft model. The cardan shaft model was designed to be as safe as possible and hence to use the most suitable shaft, with the best engine and the safest material.

Figure 3 Automotive cardan shaft model
Source: Own Elaboration (Solidworks)

Dynamic simulation

For the development of the dynamic simulation with the automotive cardan shaft (axis 1) and the motorbike cardan shaft (axis 2), the boundary conditions were established to simulate a greater precision analogous to what it would be in real life with the Blue Core engine. Angular displacements, angular velocity and angular acceleration were measured.

The gravitational constant is set to 9.81 m/s^2, the motor torque of 12.8 N-m at the output flange, at a constant speed of 4500 RPM, due to hardware limitations, the simulation time was defined from 0 to 0.50 seconds (Shigley *et al*., 2019).

For the angular displacement, the two crossheads of the automotive cardan shaft were selected, as these are the elements that generate a greater displacement in the rotation as shown in the tracings; in Figure 4 it can be seen that the crossheads have a similar displacement, indicating that there is no considerable offset that could affect the movement of the shaft.

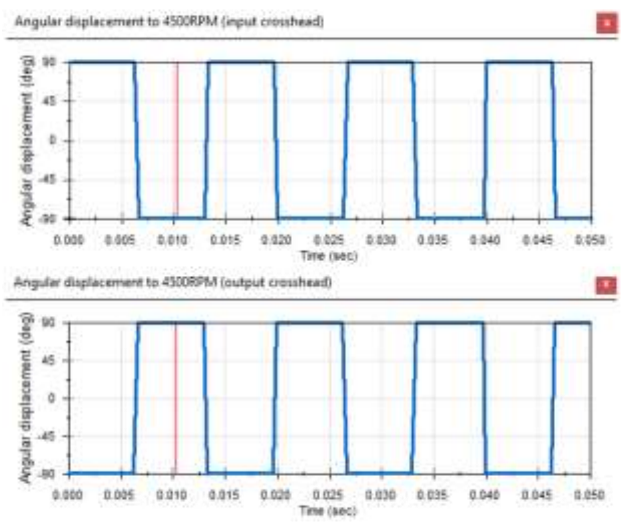

Figure 4 Angular displacement trace
Source: Own Elaboration (Solidworks)

Table 3 shows the results of the Blue Core motor with the two axes, as well as the angular velocity, maximum and minimum torque and energy consumption, which are similar to the values provided by the manufacturer.

Blue Core	Axis 1	Axis 2
Angular velocity (grad/sec)	27000	27000
Minimum torque (N-m)	12.798	12.8
Maximum torque (N-m)	13.03	13.07
Minimum power consumption (Watt)	6031	6031
Maximum power consumption (Watt)	6140	6159

Table 3 Dynamic results Blue Core engine
Source: Own elaboration (Word)

Table 4 shows the dynamic results of the CBF125 TWISTER 2022 engine, obtaining results similar to those of the manufacturer.

CBF125 TWISTER 2022	Axis 1	Axis 2
Angular speed (grad/sec)	30000	30000
Minimum torque (N-m)	10.1	10.1
Maximum torque (N-m)	10.12	10.12
Minimum power consumption (Watts)	5293.5	5287
Maximum power consumption (Watt)	5293.6	5301

Table 4 CBF125 Twister 2022 engine dynamic results
Source: Own Elaboration (Word)

Structural simulation

The structural simulation by movement loads, demanded a high hardware performance, to optimise the study, a solution is to analyse a time range in the simulation, that is to say, to extend the function, this is done after obtaining the dynamic traces and identifying that the function is periodic. The selected time range is from 0.030 to 0.040 seconds, having a very small variation, the time of 0.035 seconds was selected for the demonstration of the results (Le *et al.*, 2020).

Figures 5, 6 and 7 show the results of the Von Mises stress, displacement and factor of safety for the Blue Core engine with the automotive cardan shaft and Alloy Steel material.

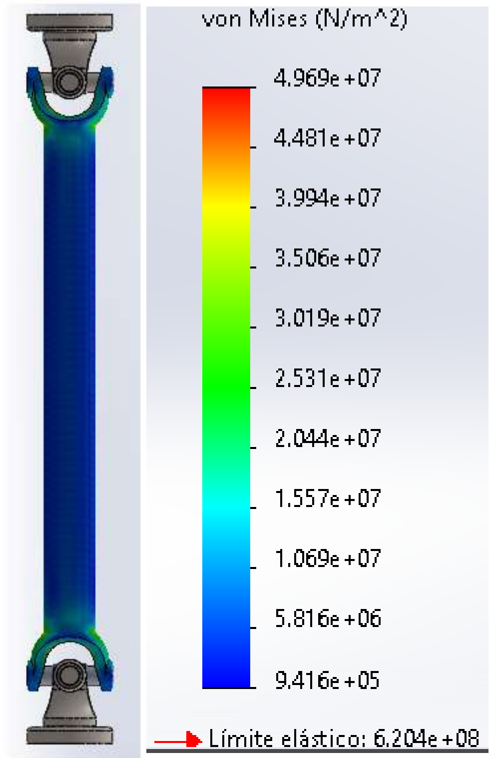

Figure 5 Von Mises stress, Blue Core engine, alloy steel
Source: Own Elaboration (Solidworks)

As shown in Figure 5, using the Blue Core motor, the maximum stress is 49.69 MPa and the minimum is 0.9416 MPa for the alloy steel automotive cardan shaft.

The maximum displacement is 7.34E-02 mm and the minimum displacement is 1.59E-04 mm, as can be seen in Figure 6.

Figure 7 shows the factor of safety, with the minimum factor of safety being 12.49, which is developed at the ends of the cardan shaft. This is reasonable, as the ends are where the power is transmitted due to the flanges and the highest stress concentrations are generated due to the change of geometry in the model.

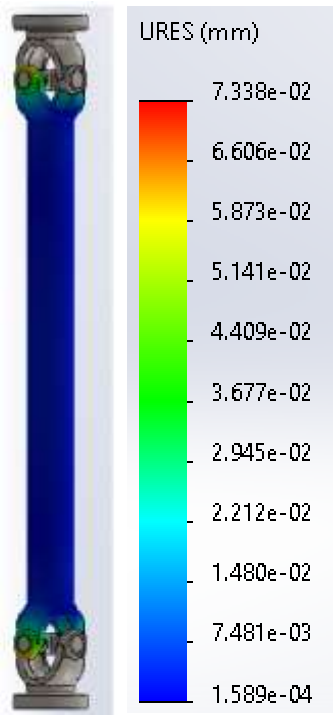

Figure 6 Displacement, Blue Core engine, alloy steel
Source: Own Elaboration (Solidworks)

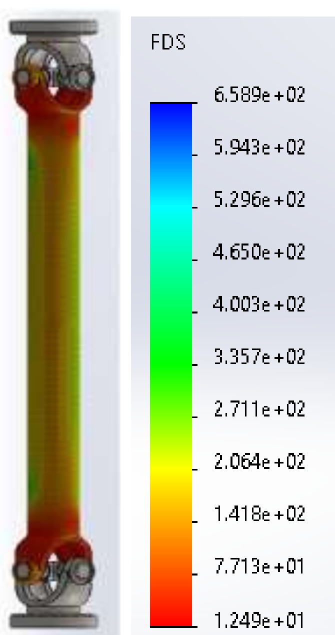

Figure 7 Factor of safety, Blue Core engine, alloy steel
Source: Own elaboration (solidworks)

Structural simulation was also carried out using moving loads to the 1045 Steel automotive cardan shaft, with the Blue Core motor at 12 N-m and 4500 RPM.

Figure 8 shows the Von Mises stresses on the 1045 steel automotive cardan shaft, the minimum stress is 0.9635 MPa and the maximum is 50.60 MPa, giving very similar stresses as with the alloy steel.

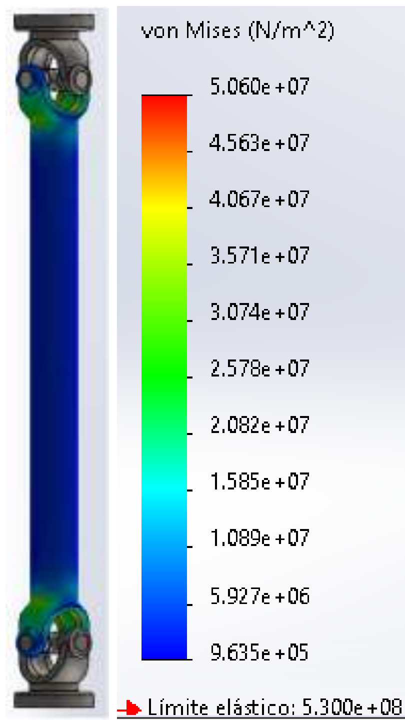

Figure 8 Von Mises stress, Blue Core engine, steel 1045
Source: own elaboration (solidworks)

The maximum displacement obtained in the 1045 steel is 7.66E-2 mm and the minimum is 1.65E-4 mm, giving larger displacements when compared to those obtained in the simulation with the alloy steel, as can be seen in Figure 9.

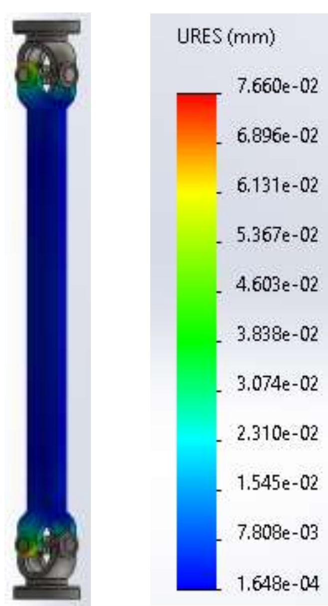

Figure 9 Displacement, Blue Core engine, steel 1045
Source: Own Elaboration (Solidworks)

Figure 10 shows the safety factor with the Blue Core motor and the automotive cardan shaft made of 1045 material, obtaining a minimum safety factor of 10.48, which is developed at the ends of the shaft.

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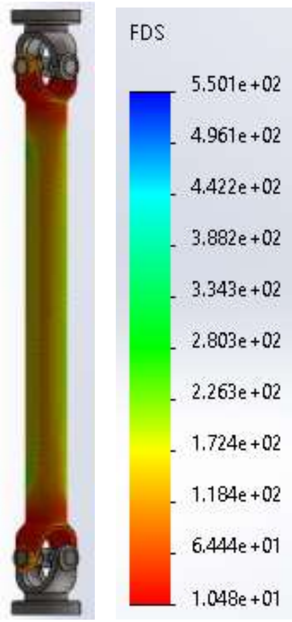

Figure 10 Safety factor, Blue Core engine, 1045 steel.
Source: Own Elaboration (Solidworks)

The same simulations were carried out for the cardan shaft of the trolley motor, using the Blue Core motor and the two types of steel, alloy and 1045; Table 5 shows the results of the structural simulations, such as: Von Mises stress, displacements and safety factor.

Blue Core Engine	Alloy steel shaft 2	AISI-1045 steel shaft 2
Von mises minimum (MPa)	0.6687	0.6685
Von mises maximum (MPa)	223.20	226.60
Minimum displacement (mm)	4.16E-05	4.72E-05
Maximum displacement (mm)	5.03E-01	5.24E-01
Minimum Factor of Safety	2.779E+00	2.339E+00
Maximum factor of safety	9.278E+02	7.928E+02

Table 5 Blue core engine structural results
Source: Own Elaboration (Word)

As can be seen in Table 5, the results for the drive shaft of the motor trolley with the Blue Core engine, the minimum Von Mises stress for the alloy steel is 0.6687 MPa, while the minimum for the 1045 steel is 0.6885 MPa, the maximum displacements for the alloy steel and 1045 are 5.03E-01 and 5.24E-01 mm, respectively. The minimum factor of safety was obtained for 1045 steel as 2.339, and for alloy steel as 2.779.

Once the simulations were carried out with the Blue Core engine, the same simulations were carried out, but now with the CBF125 TWISTER 2022 engine, at 10.11 N-m at 5000 RPM, using the two types of cardan shafts, with the two types of material, alloy steel and 1045 steel. The results of these simulations are presented in Table 6.

CBF125 TWISTER 2022	Alloy steel shaft 1	AISI-1045 steel shaft 1	Alloy steel shaft 2	AISI-1045 steel shaft 2
Von mises minimum (MPa)	0.8593	0.8748	0.8494	0.8496
Von mises maximum (MPa)	61.39	62.46	275.60	279.80
Minimum displacement (mm)	1.12E-04	9.43E-05	5.08E-05	5.71E-05
Maximum displacement (mm)	8.81E-02	9.19E-02	6.21E-01	6.47E-01
Minimum Factor of Safety	1.011E+01	8.486E+00	2.251E+00	1.894E+00
Maximum factor of safety	7.220E+02	6.059E+02	7.304E+02	6.238E+02

Table 6 Structural results CBF125 TWISTER 2022 engine
Source: Own Elaboration (Word)

The minimum Von Mises stress is 0.8494 MPa and is obtained with the trolley cardan shaft and the alloy steel. The maximum displacement was obtained with the motor trolley shaft and 1045 steel which was 6.47E-01 mm, likewise, with this shaft the minimum safety factor of 1.89 was obtained, these results are using the CBF125 Twsiter 2022 engine. For the same data, the maximum total deformation, the maximum Von Mises stress and the minimum safety factor can be seen.

In Figure 11, you can see the comparison of all the simulations for the Blue Core (simulation 1) and CBF125 Twister 2022 (simulation 2) engines with the automotive cardan shaft and the motorbike trolley cardan shaft, as well as the different types of materials used, alloy steel and 1045 steel. The maximum Von Mises stress was obtained in the simulation of the CBF125 Twister 2022 engine, with the automotive cardan shaft and AISI 1045 steel, being 279.80 MPa. With the alloy steel material, it gave a stress of 275.60 MPa, slightly less than the previous one. While the lowest Von Mises stress was for the Blue Core engine simulation, with the automotive shaft and alloy steel, resulting in 49.69 MPa. The above is shown in Figure 11.

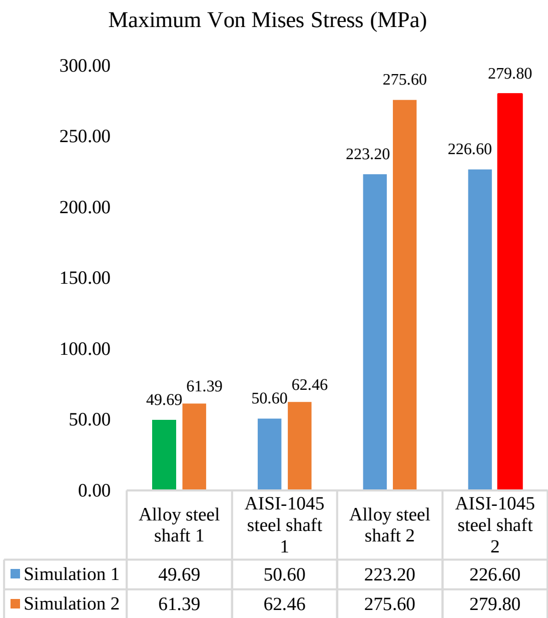

Figure 11 Von Mises stress (MPa)
Source: Own Elaboration (Excel)

Figure 12 shows the maximum displacements with the two types of motors used, the maximum deformation was 0.647 mm, with the CFB125 Twister 2022 motor, the AISI 1045 steel and the cardan shaft of the motor car. For the simulation of the Blue Core engine, alloy steel and the automotive cardan shaft, a minimum deformation of 7.34E-02 mm was obtained.

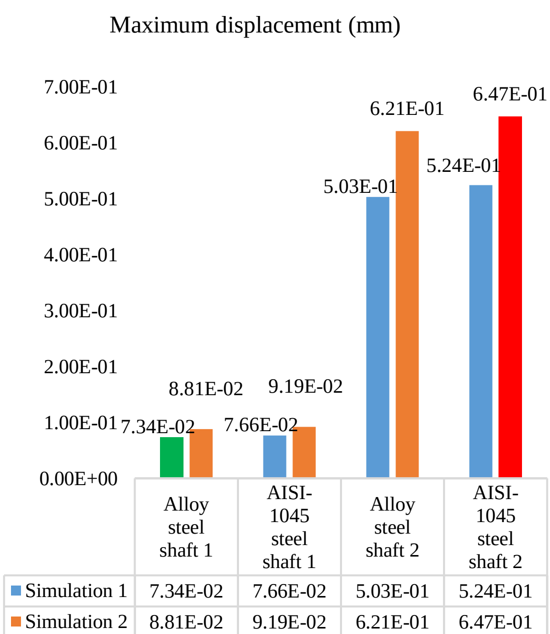

Figure 12 Dynamic displacements (mm)
Source: Own Elaboration (Excel)

The minimum safety factor was 1.894 with the CBF125 Twister 2022 engine in the automotive cardan shaft with AISI 1045 steel material. The simulation with the Blue Core engine and the automotive cardan shaft with alloy steel achieved a minimum safety factor of 1.249E+01. Both safety factors are acceptable as they are within the established range. However, the latter has a higher structural safety criterion for the boundary conditions at which both shafts were simulated, as can be seen in Figure 13.

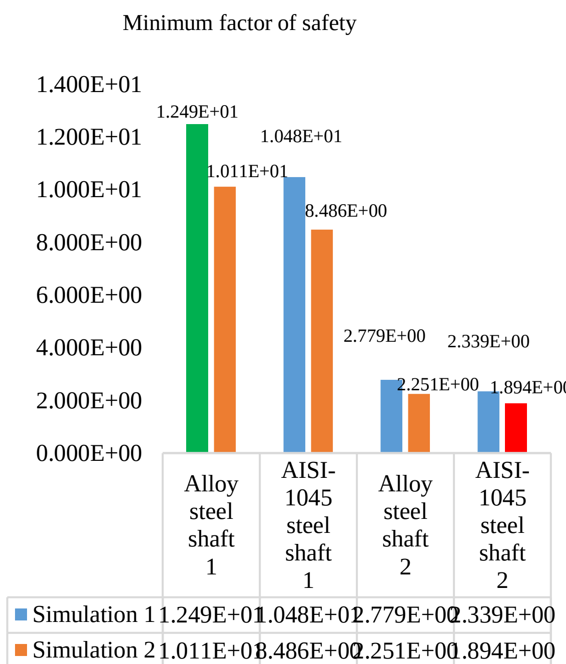

Figure 13 Safety factor
Source: Own Elaboration (Excel)

Conclusions

Based on the results obtained and having analysed each of the graphs above, by means of the structural simulation of dynamic loads, the structural element that stands out with the minimum Von Mises stress, the minimum deformation and the minimum safety factor, the automotive cardan shaft model with the alloy steel material and the simulated boundary conditions described in the specifications of the Blue Core engine (simulation 1), can be distinguished.

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