

Compression Behavior of DIN C10C and SAE-AISI 1010 Steels During Riveting of Clutch Disc Spacer Bolts: Experimental and Computational Analysis

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ABSTRACT

The rapid growth of the emerging markets has pushed the automotive original equipment manufacturers to relocalize production to reduce manufacturing and logistic costs. To ensure an efficient and flexible supply chain, local suppliers are appointed. However, the characteristics of materials available in each region may have minor differences, and when geometry and process design recommendations that were developed for certain materials are implemented for materials under a different regional standard, different results are obtained. Such is the case of the clutch disc spacer bolt, in which its compression during riveting has a direct effect in the noise and vibration isolation of the vehicle. It has been reported that spacer bolts produced with materials considered to be equivalent in Europe and North America (DIN C10C and SAE-AISI 1010 steels) behave different during riveting, even though they have very similar chemical compositions and are delivered with a similar UTS and ductility. The aim of this paper is to compare the compression behavior of both materials during riveting, and to explain the factors affecting the material response during compression that lead to differences in the final geometry. Finite element simulations are used for the analysis and validated experimentally by a controlled prototype production. Results indicated that 1010 steel compresses in average 0.3 mm more than C10C steel, caused by the yield stress difference. Experimental results were within the simulation results range. Microstructural analysis and microhardness measurements are reported in order to explain the deformation mechanisms. Finally, a change in the spacer bolt barrel dimension prior riveting is proposed based on finite element simulations to overcome their differences and produce a rivet under specification.

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INTRODUCTION

The powertrain is the group of mechanical elements that ensure the vehicle main function, to move, by reducing rotational speed, increasing the torque, and changing the torque flow direction. Over the years several powertrain architectures have been developed by incorporating new technologies such as the automatic transmission, double clutch, continuously variable transmission CVT, among others. However, manual transmissions continue to prevail because of its relative low cost and high efficiency. Among all the elements in the manual transmission systems (engine, flywheel, clutch, gearbox, differential), the spacer bolt is a component of the clutch disc. This component has three main functions: 1) to hold together the plates that maintain the damper coil springs into place (Fig 1a), 2) to limit the angular wind up to avoid coil spring breakage (Fig 1b), and 3) to ensure a correct hysteresis behavior of the clutch disc. The hysteresis behavior is dependent on the friction force between the components inside the clutch disc. The component that controls this force is the diaphragm spring that is designed to have a determined force at the assembly working position in part defined by the spacer bolt barrel height (Fig 1c). Since the spacer bolt barrel height has an impact in

the hysteresis characteristic of the clutch disc, it also impacts the engine vibration isolation in the vehicle, and thus it is important to ensure that the bolt dimensions after riveting are accurate.

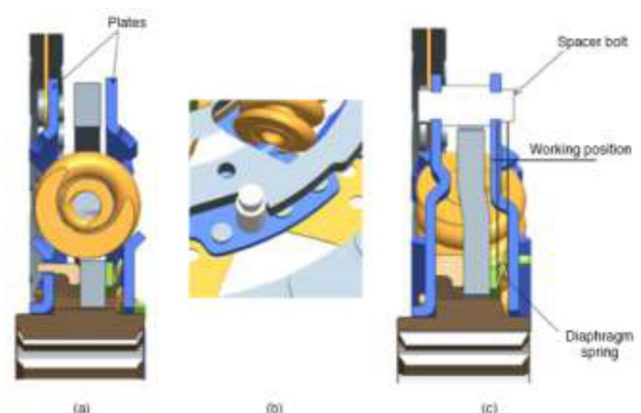


Figure 1. Main functions of the clutch disc spacer bolt: (a) hold together plates that maintain coil spring into place, (b) limit angular wind up to avoid coil spring breakage, and (c) define the diaphragm spring force at the assembled working position.

Because of the rapid growth in vehicle sales in emerging markets, Original Equipment Manufacturers (OEMs) have been pushed to relocalize production in order to reduce manufacturing and logistic costs. To ensure an efficient and flexible supply chain, local suppliers have been appointed. However, the characteristics of the materials available in each region may have minor differences that impact greatly in some specific applications. When geometry and process design recommendations that were developed for certain materials are implemented for materials under a different standard, different results are obtained. Such is the case of the clutch disc spacer bolt, in which its functional geometry is defined after the riveting process. It has been reported that spacer bolts produced with materials considered to be equivalent (DIN C10C and SAE-AISI 1010 steels) behave different during riveting, even though they have very similar chemical compositions and are delivered with a similar UTS and ductility.

The aim of this paper is to compare the compression behavior of both materials during riveting, and to explain the factors affecting the material response during compression that lead to differences in the final geometry. Finite element simulations are used for the analysis and validated experimentally by a controlled prototype production. Finally, a change in the spacer bolt barrel dimension is proposed based on finite element simulations to overcome the different compression behavior of both materials and obtain a product that is within specification.

MATERIALS

The behavior during riveting of steels DIN C10C and SAE-AISI 1010 is compared in this study. C10C steel was selected from the DIN 660 standard for round head rivets [1], while 1010 steel is the equivalent material offered by local suppliers in SAE-AISI standard in North America. As shown in Table 1, the chemical composition of both materials is very similar. The materials differ mainly in the silicon and aluminum composition, but the values are not considered to be relevant to the mechanical properties.

Table 1. DIN C10C and AISI 1010 steel chemical composition.

Material	C	Si max	Mn	P max	S max	Al
C10C	0.08-0.12	0.1	0.3-0.5	0.025	0.025	0.02-0.06
1010	0.08-0.13	-	0.3-0.6	0.03	0.05	-

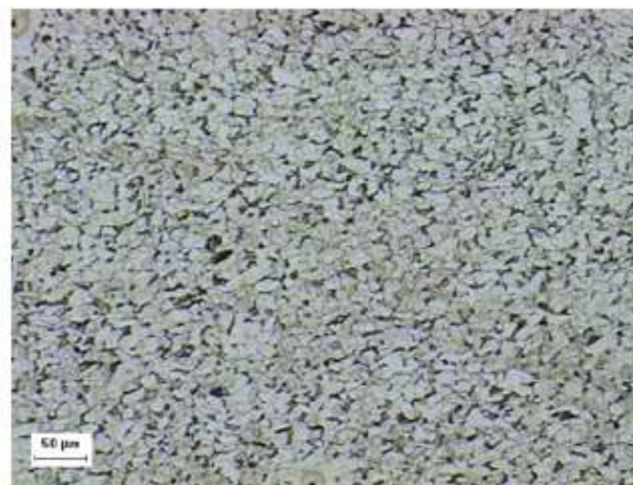
Figure 2 shows the microstructure of both steels, which is mainly constituted by fine perlite colonies in a ferritic matrix, typical of low carbon steels. Grain size was evaluated according to the ASTM-E112 standard [2], and for both materials it was found to be 8.0-8.5. The level of inclusions was estimated according to the ASTM-E45 [3] standard. A 0.5 level of sulfides, silicates, aluminates and globular oxides was also found for both materials. With this in mind it is understandable to suggest that AISI 1010 steel is equivalent to DIN C10C as offered by local suppliers.

However, the mechanical properties of these materials also depend on the delivery condition (i.e. untreated, peeled, cold drawn), and certain differences may arise which are not evident in the microstructure or chemical composition. Although materials are

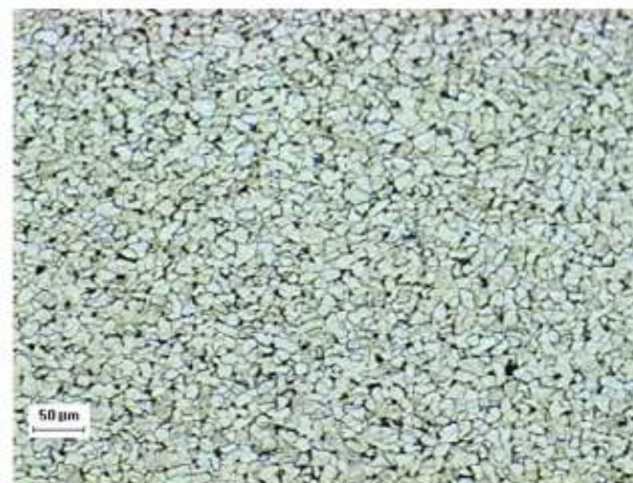
provided according to the customer specifications, usually an specified ultimate tensile strength (UTS), or ductility, some other properties such as the yield stress may be different from one material to another even though their UTS or ductility are similar. This will have a significant impact on the compression behavior of the spacer bolt and therefore, compression tests were performed on both materials to evaluate their mechanical properties.

COMPRESSION BEHAVIOR OF DIN C10C AND AISI 1010 STEELS

Compression tests were performed in an Instron 4500 universal testing machine until a force of 80 kN was reached at a speed of 5 mm/min. Tests were performed at room temperature. Three replicate samples were used for each material. Test specimens were machined from existing spacer bolts, having an initial diameter (D_0) of 8.95 mm and an initial length (L_0) of 8.95 mm. Riveting is performed without lubrication and so was the compression test.



a.



b.

Figure 2. (a) DIN C10C and (b) SAE-AISI 1010 microstructure.

Figure 3 shows the compressed samples of both materials. A simple view suggests that both materials compressed similarly, with barreling as the deformation mode. With a length-diameter ratio (L/D) of 1, a barreling deformation mode was expected according to the ASM handbook [4]. Final length (L_f) and diameter (D_f) were measured and average strains calculated. Results are summarized in Table 2. Both materials have a longitudinal strain (ε_{long}) of approximately -40% and a lateral strain (ε_{lat}) of approximately 32%, suggesting that both materials are equivalent under compression, expecting a similar behavior during riveting.

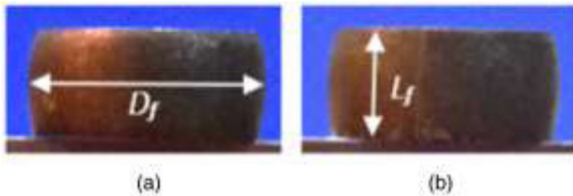


Figure 3. Barreled (a) DIN C10C and (b) AISI 1010 specimens after compression tests.

Table 2. Longitudinal and lateral strains of materials C10C and 1010 during compression tests.

Material	Specimen	Longitudinal Strain [%] ($L_f - L_0$) / L_0	Lateral Strain [%] ($D_f - D_0$) / D_0
C10C	1	-39.02	30.36
	2	-40.76	33.07
	3	-40.76	32.89
	Mean (Exp)	-40.18	32.10
	FEM	-39.22	29.39
1010	1	-39.87	31.73
	2	-40.09	31.77
	3	-39.56	33.78
	Mean (Exp)	-39.84	32.43
	FEM	-38.44	28.83

Figure 4 shows the true stress-strain curve for C10C and 1010 steel. The true stress σ_T and true strain ε_T were obtained with the following equations

$$\sigma_T = \sigma(1 - \varepsilon); \varepsilon_T = \ln(1 - \varepsilon) \quad (1)$$

where

$$\sigma = \frac{F}{A_0}; \varepsilon = \frac{\delta}{L_0} \quad (2)$$

where σ is engineering stress, F is the applied compression force, A_0 is the initial cross sectional area, ε is engineering strain, and δ is the sample compression. Stand stiffness was estimated according to the methodology proposed in the ASM Handbook - Mechanical Testing an Evaluation [4]. The elastic modulus of both materials was assumed to be the theoretical value for unalloyed steel: 210 GPa.

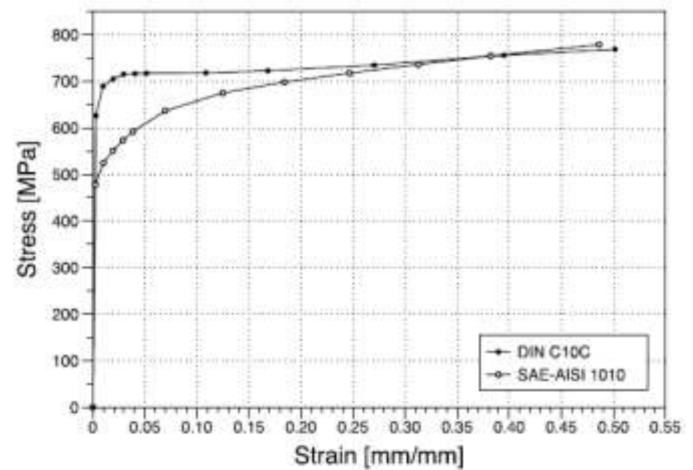


Figure 4. True stress-strain curves of steels DIN C10C and AISI 1010 obtained from compression tests.

As observed from Table 2 and Fig. 4, both materials have the same % of elongation and area reduction (indicated by the longitudinal and lateral strains), and also the same compressive strength. As mentioned above, these two parameters, elongation and strength, are the ones usually specified by the local suppliers and thus the materials are considered equivalent. However, a different behavior is observed at yielding. From the curves in Fig. 4, yield stresses were calculated: 628 MPa for C10C steel and 479 MPa for 1010 steel. Note that if the stresses on the spacer bolt during the riveting process are below 730MPa, a spacer bolt of material 1010 will deform more than one of material C10C.

COMPRESSION TEST SIMULATION

A finite element simulation using ANSYS Workbench 13.0 was performed to model the compression test of both steels with the aim of developing a tool for predicting the compression of both materials during riveting. A 2D surface model was created in Pro-E Wildfire 4.0 and exported to ANSYS Workbench. It consists of three separate surfaces that represent the test specimen and the bench plates. The mesh element type used for this analysis is mainly hexahedron with a size of 0.5mm. The element size was chosen to ensure the analysis convergence. Tetrahedron elements are present in the transitions.

The true stress-strain curves obtained from the compression tests were assigned to the specimen. A linear structural steel was assigned to the bench plates as they are considered to be more rigid and are not expected to deform permanently. The materials used in the model were considered isotropic, homogeneous, and free of residual stresses.

Boundary Conditions

The bottom plate was fixed to avoid any undesired displacement. A ramp force of 80 kN was applied to the top plate, which was only allowed to move downward. The ramp force was applied during the average test time for both materials, 20 s, which was obtained from the compression tests. The force was released when it reached 80 kN.

Frictional connections are declared between the plates and the specimen, so a barreling deformation is obtained. The friction coefficient used for the analysis is 0.2 based on a similar analysis.