Effect of gas tungsten arc welded 308 and 409 stainless steels on their mechanical properties

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Stainless steels (SS) in automobile sector were previously incorporated mainly due to their decorative applications. Nowadays, their functional and specific characteristics make them more required and employed in this sector. Especially attention from automotive manufacturers has been paid in order to improve the engine efficiency and reduce weight of the vehicle, stainless steels result to be enabled due to their high strength mechanical characteristics, energy absorption capability, fatigue and corrosion resistance; besides their ductility which is traduced to an easy manufacturability. When welding is applied some of their characteristics may be affected and could decrease their mechanical properties. In attempt to avoid these circumstances, welding experimental practices must be carried out. In this study plates of 308 austenitic and 409 ferritic stainless steels were welded by Gas Tungsten Arc Welding process with different current values in order to get their mechanical properties behavior. Tensile tests were performed, it results that for austenitic stainless steels welds all failed in the fusion zone presenting ductile behavior; however, for ferritic stainless steels brittle fracture was observed. The maximum value of hardness for 308 austenitic SS was founded in the base metal, instead for 409 ferritic SS was reached at the heat affected zone.

This study can be a practical guide in the selection of adequate joining methods in order to determine the more efficient to use in structural automotive industry.

Keywords: Stainless steel - GTAW - Mechanical properties

INTRODUCTION

Automotive industry development is constantly pursuing on the conductor's safety and the weight reduction of the vehicle. The material selection is primordial in engineering in order to have an adequate and profitable product, metal matrix composites, advanced high strength steels, polymers and ceramic composites, and stainless steels are employed to fulfill these sector requirements. Once, stainless steels usage in automotive sector was ornamental and simply decorative, wheel covers and trim with minor amount used for valves and hose clamps [1].

For instance austenitic stainless steels are commonly seen at chemical industries in tanks or vessel internals, although into furnaces and jet engines were cryogenic temperatures are required, while, ferritic stainless steels are more employed on pulp and paper industry and refinery [2; 3]. This is due to their high temperature resistance, corrosion resistance, fatigue resistance and energy absorption capability. Hence, these properties make them able to meet requirements for automotive sector [4; 5; 6]. In 2001, Tseng described that an austenitic stainless steels shows thermal conductivity lower than carbon steels and higher thermal expansion [7]. Important considerations must be taken when welding is applied; microstructural alterations occurs and mechanical decrement properties take place if there are not adequate welding parameters. Their microstructure austenitic and ferritic depends on the balance of promoting elements of each phase [4; 8; 9], thus during welding, heating and cooling cycles can induces to new diverse phases such as martensite, and modify their mechanical properties.

In certain austenitic stainless steels welds with a completely austenitic matrix are commonly prone to hot cracking [10], and sometimes in the weld filler material delta δ-ferrite promoting elements are added in order to minimize this tendency [11]. The welding process usually more employed to joint this types of materials is the Submerged Arc Welding (SAW), with the economic disadvantage during the joint thus the high cost of the filler metal. Gas Tungsten Arc welding (GTAW) process does not require filler metal which means eminent economic advantage. This work was carried out, in order to have a deeper knowledge

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Base Metal (wt %)	C	S	Mn	P	Si	Cr	Ni	Mo	Cu	V
A 308	0,02	0,012	1.28	0.031	0,46	18.23	8.81	0.08	0.102	0.110
F 409	0,03	0,02	1,00	0,040	1,00	13,5	0,5	-	-	-

Tab. 1 - Nominal chemical composition of the austenitic 308 and ferritic 409 stainless steels base metal.

Tab. 1- Composizione chimica nominale del metallo base

on the microstructure changes on welded stainless steels with GTAW. GTAW process in ferritic and austenitic stainless steels had not reached its fully potential so far; since there is limited weldability data published literature.
This paper deals with the microstructural characterization of austenitic 308 and ferritic 409 welded stainless steels with GTAW. Mechanical testing and microstructural examinations were carried out in order to evaluate the weldments efficiency. Furthermore, their properties-microstructure relationship was analyzed and explained.

EXPERIMENTAL DETAILS

The all series experimental include 6 specimens of austenitic 308 (A 308) and 6 specimens of ferritic stainless steel 409 (F 409) sheets plates of 8" x 2.5" x 9/34 and 8" x 2.5" x 7/24 respectively, with chemical composition shown in Table 1. Mechanical properties of the both stainless steels grades are given in Table 2.

Base Metal	Yield Strength [Mpa]	Ultimate Tensile Strength [MPa]	Elongation [%]	Hardness [Hv]
A 308	205MPa	515MPa	40%	185
F 409	207MPa	380MPa	20%	184

Tab. 2 - Mechanical properties of the austenitic 308 and ferritic 409 stainless steels base metal

Tab. 2 - Proprietà meccaniche degli acciai inossidabili austenitici 308 e ferritici 409

For the weldments Argon 100% shielding gas was used to join the sheets plates for butt joints, in one pass along the longitudinal direction using manual GTAW process with a 3/8" electrode diameter, the welding parameters are given in Table 3 for each material.
All metallographic specimens were prepared using standard procedures, cross sections for optical metallography were prepared using standard techniques of polishing; for A 308 samples were etched (1/3 nitric acid, 1/3 chloride acid, 1/3 water) instead for the F 409 specimens were etched with Vilella's reagent (1 g picric acid, 5 mL HCl and 100 mL ethanol).
The welded joints were then observed through optical (OM) and scanning electron microscope (SEM) Jeol JSM-6490 LV. The SEM was equipped with an energy dispersive X-ray spectrometer, used for the chemical analysis of the welded and heat affected areas. For the microstructural analysis the software "image pro plus" was employed. The microhardness test was performed using a load of 500 g with the FM-300 equipment. The tensile strength of welded joints was evaluated by MTS QT-100 testing machine using a load of 100kNw, based in the ASTM E8-04 [12] guideline for subsize samples.

	Base Metal	Current [A]	Voltage [V]	Welding speed [mm/s]	Heat Input [J/mm]
A 308	A1	150	10	10.2	147.6
	A2	175	10	10.2	172.2
	A3	200	10	11.6	172.2
	A4	225	10	12.7	177.2
	A5	250	10	15.6	159.9
	A6	275	10	14.5	189.5
F 409	F1	150	10	5.2	289.9
	F2	175	10	6	290.7
	F3	200	10	6.4	310
	F4	225	10	6.8	327.1
	F5	250	11	6.3	439.3
	F6	275	11	8.7	345.4

Tab. 3 - Welding parameters using GTAW process in ferritic 409 and austenitic 308 stainless steels

Tab. 3 - Parametri di saldatura con processo GTAW nelle acciai inossidabili ferritici 409 e austenitici 308.

RESULTS AND DISCUSSION

a) Initial base metal microstructure

The austenitic stainless steel 308 micrograph shown in Figure 1A, is for the base metal which consists in austenitic matrix with equiaxed austenite grains and twins austenitic grains as well. Instead for the ferritic stainless steels (Figure 1B), entirely ferritic matrix is showed.

b) Welding characterization

Macrographs for the welding profiles are shown in Figure 2, in order to evidence the different welding zones including, heat affected zone (HAZ) and fusion zone (FZ) for both steels. In the of the ferritic plate grain coarsening was revealed, produced by GTAW process [13].
Figure 3 presents the microstructure for the HAZ and FZ respectively for the austenitic stainless steel, on the HAZ deformed austenitic grains due to the heat exposed by welding and some coarse grained austenite (Figure 3A). In the Figure 3B for the specimen F6 surface discontinuities on the welding in the HAZ was presented, this could be due to the temperature of the base material previously deposited weld metal is not elevated to its melting point during the welding process or for unsuitable welding conditions. Instead in the fusion zone (FZ) austenite dendrites were observed (Figure 3C).

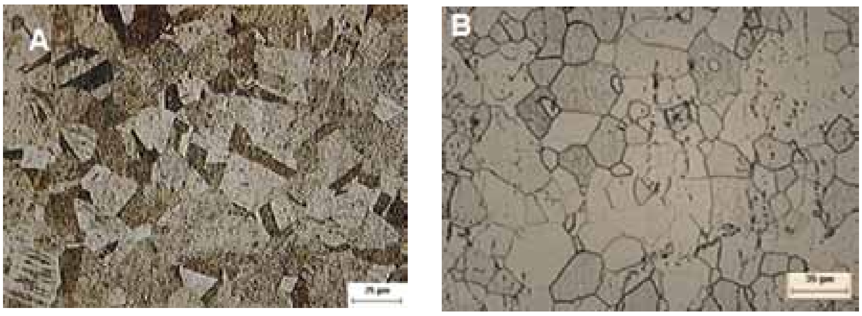

Fig. 1 - Optical micrograph for the transversal section of the a) 308 austenitic stainless steel, b) 409 ferritic stainless steel base metal.

Fig. 1 - Micrografia ottica della sezione trasversale del metallo base: a) acciaio inossidabile austenitico 308, b) acciaio inossidabile ferritico 409.

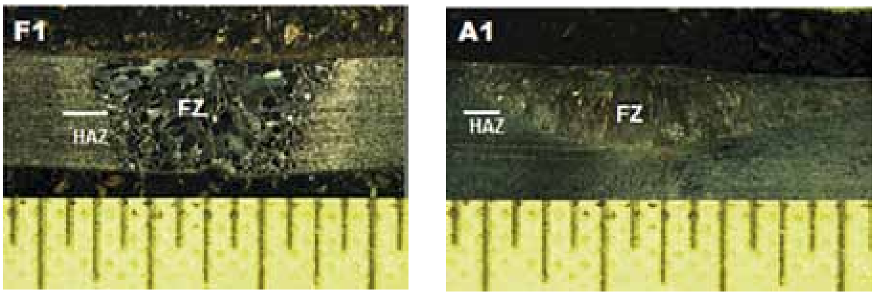

Fig. 2 - Macrographs of the welding profile, F1) F 409 and A1) A 308

Fig. 2 - Macrografie del profilo di saldatura, F1) F 409 e A1) A 308

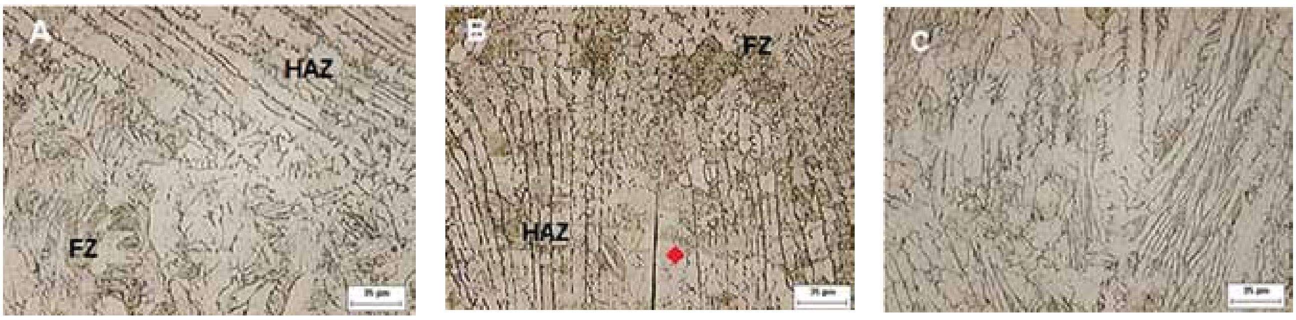

Fig. 3 - 308 austenitic stainless steel, a) HAZ in the superior side with deformed austenitic grains, b) Micrograph evidencing incomplete welding penetration, c) austenite dendrites grains in the fusion zone.

Fig. 3 - Acciaio inossidabile austenitico 308, a) ZTA nella parte superiore con grani austenitici deformati, b) Micrografia che evidenzia una penetrazione incompleta della saldatura, c) Dendriti di austenite nella zona di fusione

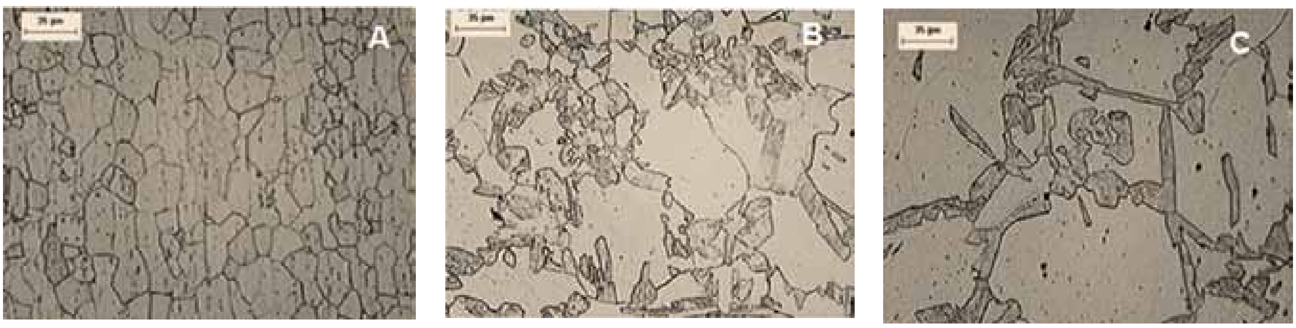

Fig. 4 - Optical micrograph: a) the microstructure is fully ferritic in BM b) ferritic matrix with islands of martensite at the grain boundaries and c) lath martensite in FZ. 200X

Fig. 4 - Micrografia ottica: a) microstruttura completamente ferritica nel metallo base, b) matrice ferritica con le isole di martensite ai bordi grano e c) lamelle di martensite nella zona fusa a 200X

The microstructural characterization of the F 409 stainless steels showed in Figure 4, the heat affected zone has martensite islands at the grain boundaries with a coarse ferrite matrix, in this case is due to the reversion to austenite when the steel is heated close to liquidus during welding transform completely to δ-ferrite growths and reversion happens. The HAZ presented in Figure 4B is for the specimen welded with the lower current, it has more martensite grains formation, which was confirmed by the microhardness test.

For the fusion zone ferrite matrix is evidence within martensite laths on their grain boundaries, being a typical microstructure for welded ferritic stainless steels.

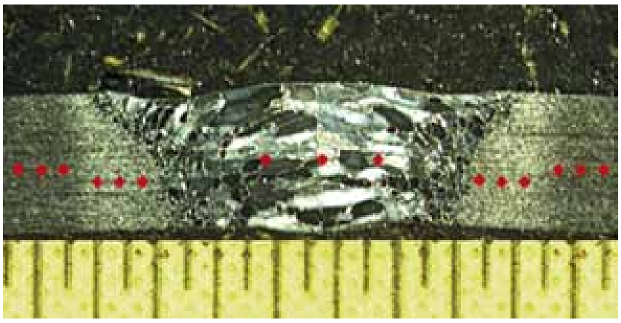

Fig. 5 - Macrograph evidencing the indentations for the microhardness test.

Fig. 5 - Macrografia delle indentazioni ottenute dalla prova di microdurezza.

c) Microhardness evaluation

Figure 5 evidence the indentations location during the measurement for the microhardness test in a representative specimen.
In the graph showed in Figure 6 for the weld cross sections, F 409 ferritic stainless steel representative specimen presents higher hardness in the heat affected zone, this confirms the OM observation were some greater martensite areas were evidenced. The maximum hardness reached is 260 HV located at the HAZ. Martensite phase which is formed in the stainless steel decrease their mechanical properties as toughness and ductility [12].
In A 308 stainless steel case the measures do not present variation between the different zones along the weld.

d) Factographic evaluation

For this study were selected 6 specimens (3 of each grade). In the scanning electron micrographs from Figure 7 the fracture for the A308 has a typical dimples which is characteristic from a ductile fracture it also evidence an appreciable plastic deformation. On the other hand, brittle behavior with chevron markings in the F 409 stainless steel was showed on Figure 8. On more profound observation, it could be notice that the fracture surface was relatively flat and there was a lack of appreciable cavitation.
The ultimate tensile strength (UTS) of the as-received stainless steels were 515 MPa for austenitic stainless steel 308 and 380 MPa for ferritic stainless steel 409, the values obtained of the welds drop under from does obtained in the base metal (365 MPa). Therefore, this evidently suggests that joining stainless steels by GTAW process conduces to a reduction in the steel properties specifically toughness and ductility. In both cases the fracture was initiated on the FZ.

CONCLUSIONS

This work performed detail experiments in order to obtain deeper information concerning joining stainless steels using GTAW process. It concludes as follows:

- Microstructural analysis indicates that, for A 308 austenitic grains on base metal was showed following coarse austenitic grains in the HAZ, and dendrites structure at the FZ was highlighted. In the case of F 409, martensitic islands were observed at HAZ which had an increment on the microhardness values. Martensite laths were found at the FZ. Furthermore, the martensite grains formed in these zones decrease their mechanical properties as showed in the factrographic analysis.
- Microhardness test confirms the microstructural observations, martensite phase in F 409 lead to an increment of the hardness particularly in the HAZ.

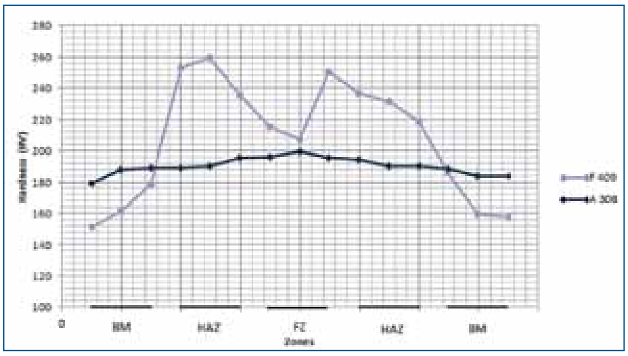

Fig. 6 - Exhibited microhardness profiles in the various regions of the welded stainless steels.

Fig. 6 - Profilo di microdurezza nelle varie regioni degli acciai inossidabili saldati.

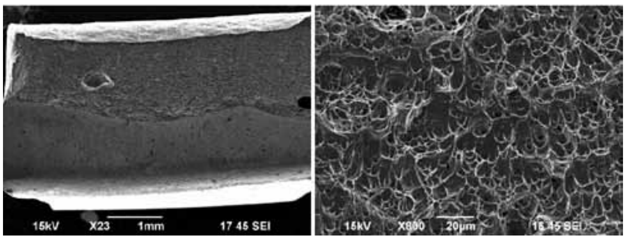

Fig. 7 - Scanning Electron micrographs of the A 308 stainless steel

Fig. 7 - Micrografie elettroniche a scansione dell'acciaio inossidabile A 308

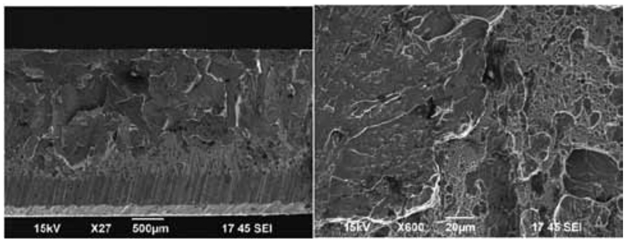

Fig. 8 - Scanning Electron micrographs of the F 409 stainless steels

Fig. 8 - Micrografie elettroniche a scansione dell'acciaio inossidabile 409 F

- In the tensile shear test values founded at literature were lower than those obtained at the test. In addition, the parameters used in GTAW welded stainless steels decrease the steel properties such as toughness and ductility.

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Effetto della saldature ad arco con elettrodo di tungsteno sulle proprietà meccaniche in acciai inossidabili 308 e 409

Parole chiave: Acciaio Inox - Saldatura - Prove meccaniche

Nel settore automobilistico, per molti anni gli acciai inossidabili sono stati principalmente utilizzati come parti decorative. Oggigiorno, invece, le loro caratteristiche funzionali e specifiche li rendono interessanti per impieghi in questo settore. I produttori di componenti automotive prestano, infatti, particolare attenzione ai materiali che possano migliorare l'efficienza del motore e ridurre il peso del veicolo e, in tal senso, gli acciai inossidabili rappresentano una scelta ottimale per questo settore, soprattutto grazie alle loro elevate caratteristiche meccaniche, di tenacità, di fatica e di resistenza alla corrosione, oltre alla loro duttilità, che si traduce in aumento della lavorabilità. Tuttavia, quando questi materiali vengono saldati, alcune delle loro caratteristiche possono peggiorare.
In questo studio, si sono analizzati giunti saldati in acciaio inossidabile austenitico AISI 308 e in acciaio inossidabile ferritico AISI 409, realizzati attraverso processo di saldatura ad arco con elettrodo di tungsteno (Gas Tungsten Arc Welding – GTAW) e utilizzando differenti valori di corrente al fine di determinarne il loro comportamento dal punto di vista delle proprietà meccaniche. Le prove di trazione eseguite sui talloni di saldatura hanno evidenziato un comportamento duttile per gli acciai inossidabili austenitici, mentre per gli acciai inossidabili ferritici si è osservata rottura di tipo fragile. Il valore massimo di durezza è stato riscontrato nel metallo base per l'austenitico 308 e nella zona termicamente alterata per il ferritico 409.
Questo studio può essere una guida pratica nella selezione dei metodi di giunzione adeguati al fine di determinare il più efficace nell'industria automobilistica.