MECHANICAL PROPERTIES OF COLD METAL TRANSFER (CMT) WELDED 202 AND 304 STAINLESS STEELS

PRATEEK RAJ & N. YUVARAJ

Department of Mechanical Engineering, Delhi Technological University

ABSTRACT

Welded joints of dissimilar stainless steel sheets have many industrial applications due to their cost effectiveness, light-weight, and high efficiency. Thin austenitic stainless steel sheets of different thicknesses are extensively used in the automation industry. Conventional welding techniques due to their high heat input and high spatters have always posed problems such as burn-through and distortion for welding these joints of thin austenitic steels. The CMT welding technique is effectively used for the joining of thin sheets due to its characteristics of lower distortion rate and low heat input. In this research work, austenitic stainless steels of grade SS202 and SS304 of thickness 1.2 mm and 2 mm respectively were welded by CMT welding technique and studied the mechanical characteristics of dissimilar stainless steel joints. Taguchi L9 optimization technique was used to find the optimized process variables for obtaining the maximum tensile strength. The maximum tensile strength of dissimilar joint welded at 115 A current, 4 mm/s welding speed, and 10% arc length correction factor was found to be 291 MPa. The maximum micro-hardness value of the weld zone was achieved and the lower value was observed in the heat-affected zone (HAZ). The X-ray diffraction (XRD) technique was utilized to detect the residual stresses of the welded joint. The residual stress was observed in compressive nature in the weld zone and base plate and of tensile nature in the heat-affected zone (HAZ). CMT welding process can produce high strength dissimilar austenitic steel joints of different thicknesses.

KEYWORDS: CMT; SS 202/304; Tensile Strength; Hardness; Residual Stresses

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INTRODUCTION

Fusion welding is considered as one of the most important techniques for the manufacturing of various components. Mostly a complete product may require varied properties at different positions like one area may need to be corrosion resistant while the other must be resistant to heat. One area may require high toughness while others may require high strength. It is very difficult to manufacture any product without using the joining process due to these technological limitations. Several parts of the products are typically assembled by the fusion practices and mostly help to fabricate economically [1]. Joining different metals is preferred to help in giving benefits of various materials and that offer distinctive solutions to different engineering requirements [2]. A reduction in weight and cost of the product without hindering the structural requirements and safety is one of the basic advantages of fusing different materials

There are many joining processes for dissimilar materials that have gained remarkable consideration in recent years. The dissimilar fusion weld must acquire satisfactory tensile and ductility test results so that the joint will be successful within the weld [3]. MIG/MAG welding technique is the most preferable process for the joining of dissimilar ferrous and non-ferrous metals due to its supreme weldment characteristics. This method is especially preferred in applications related to the automotive industry. However, with the recent shift of these industries

towards environmental sustainability and safety of passengers, different grades of steel are now being used for fabrications. Thin sheet materials alloys have a high coefficient of thermal conductivity and thermal expansion and so they pose some problems like burn through and distortion during arc welding. Welding dissimilar materials of different thicknesses having limitations with the conventional welding process due to high heat input and high spatter. Controlled heat input is an essential parameter to avoid such difficulties [4,5]. Thus a need for a welding technique arises which can be used to join thin sheets and eradicate these problems. CMT techniques lessen these difficulties to a great extent. CMT welded joint has narrow HAZ with lesser distortion makes this technique preferable for joining thin plates with improved productivity [6].

Cold Metal Transfer (CMT) welding is a newly introduced process of joining thin sheets based upon the conventional short-circuiting (CSC) transfer technique established via "Fronius of Austria". It is a technological enhancement to Gas Metal Arc Welding (GMAW) process and is highly superior to GMAW in terms of lesser spatter, distortion, burns-through, and welding cost due to its unique feature known as low heat input. In this welding process, as the arcing starts the electrode moves toward the weld puddle. As the tip of the electrode interacts with the molten metal within the weld pool, an arc is extinguished. The value of current reduces to a non-zero value and this in a way circumvents the chances of spatter. The dropped welding current value results in a significant reduction in the thermal heat input. This becomes the most favorable conditions and a feasible technique to weld thin sheets with no or very less distortion, a lower rate of dilution and lower stresses in the weld zone. It also provides high gap bridge-ability which is highly appropriate for automation. CMT welding is an automatic welding technique having a controlled deposition of material during the short-circuiting of the work-piece to an electrode and is well described for its working with a low heat input [7]. This results in less damage to the base metal, lower deformation, and residual stress. In a conventional arc welding process, the filler wires move continuously in the outward direction till a short-circuit takes place. Whereas in a CMT process, the filler wire is both pushed as well as retracted during welding, and thus it is called an intelligent system. In this process, the movement of the feeding wire with an oscillating frequency up to 70 Hz is mostly used [8].

Stainless steels have gained popularity as one of the most useful materials in industrial applications due to high resistance to corrosion. Their exceptional physical properties and design codes have made them functional in engineering applications such as structural applications, heat exchangers, and thermal power plants [9-13]. Yan et. al. (2010) [14] reported that the physical and metallurgical properties of the stainless steel TIG welded joint improved due to the presence of delta ferritic and gamma ferritic phases. During diffusion, the transformation of the austenitic phase to martensite occurs and the martensite phase improves high strength [15]. Amongst the various grades of austenitic steels available, SS304 a prominent member of 300 series is an important and most used grade due to its good corrosion resistance, higher strength, and ductility. SS202 is one of the most preferred stainless steel of the 200 grade series. They are similar to 300 series sheets of steel except for the low nickel content in them. SS 202 steel grade is economical material with the use of extensive applications due to the property of excellent toughness at a lower temperature. The welding of dissimilar grades of SS304 and SS202 has an excellent future scope and industrial applications. Both SS304 and SS202 are austenitic grade steels containing gamma iron under equilibrium cooling conditions. But during rapid cooling, an incomplete transformation occurs which leads to the formation of some meta-stable comprising delta iron [16-17]. The physical properties of inoconel 718 welded with SS316 have concluded that dissimilar weld gave a higher tensile strength than the parent SS316 metal [18]. Investigations and analysis have shown that most of the failures occurred in the heat-affected zone (HAZ) [19]. Sathiyat. al. (2005) [20] have studied the friction welding of SS 304 and concluded based on fractography that fissure occurred most of the time at the joint zone rather than the base metal. Tensile reports show an

inverse relation between friction time and joints strength. Kumaret. al. (2016) [21] in his experimentation on the effects of CMT welding process on aluminium found that an increased heat input and better fluidity can be achieved at a lower welding speed. Varghese et. al. (2019) [22] in his experimentation of coating in conel 617 M on austenitic stainless steel by CMT welding process found a direct relationship between the heat input per unit length and the welding current. Sammaiahet. al. (2010) [23] in his study on metallurgical properties of friction welded aluminium and austenitic steels showed increased tensile strength and reduced toughness with an increase in the pressure due to friction. Mishra et. al. (2014) [24] in his investigations about the strength of mild steel welded with different grades of steel found that the welded joints of SS 202 and mild steel gave the best tensile strength value with TIG and MIG welding. Proper selection of filler wire is an important criterion in fusion welding. The strength and hardness of the welded zone depend upon the selection of the filler wire. SS308 filler wire is the most suitable and recommended filler wire material for joining SS304, SS32, and SS347 [25]. Fusion welding depends on various input variables such as welding current, voltage, wire feed rate, welding speed, contact tip to workpiece distance (CTWD), etc. Arc length also controls the microstructure and the strength of the weld joints. The arc length correction while joining must be non-linear and results in a controlled dilution in the weld zone which has an advantage during the joining of sheets [26]. Most of the investigations on the welding are carried on the sheets or plates of similar equal thickness. Though, most of the welding required between the automotive parts is between materials of dissimilar thickness [27-28].

Joining dissimilar grades of steel is difficult due to the difference in melting temperatures. The different thermal conductivities and uneven temperature distribution on the weld surface result in the generation of residual stresses. The residual stresses are the internal stress that remains in the bodies when subjected to uneven or non-uniform temperature conditions when no external load is applied [29-32]. These are macroscopic stresses and static quantities, the value of which varies from zero to the material yield point.

The measurement of residual stress in the welded joint is an important factor for evaluating the mechanical characteristics of materials. The distribution and location of the residual stresses, types of stress in the material and, fatigue properties in specimens can be predicted easily [33-34]. The residual stresses are also likely to change the vulnerability for various modes of failures such as corrosion fatigue stress, corrosion fracture, and cracking. X-ray diffraction method is used for measuring the residual stresses and for analyzing the mechanical structures. The static behavior can be studied from a microscopic and macroscopic level change [35].

From the literature welding of dissimilar austenitic steel has become challenging and more investigations require for maintaining perfect arc length and higher edge tolerances. For welding of thin dissimilar materials from conventional MIG welding is a difficult task. CMT welding has become more popular for welding of thin sheets which is required for most industrial applications. In the present work, SS 304/202 and thickness of 2 mm and 1.2 mm respectively were welded. The Taguchi optimization technique is an effective method for finding the optimized parameter along with their relationship [36]. In this study, Taguchi L9 method is adopted for finding the optimized welding parameters in order to achieve the maximum tensile strength of the welded joint. The mechanical characteristics such as tensile strength, hardness, and, residual stresses of the welded joint were investigated.

EXPERIMENTAL PROCEDURE

Material and Methods

In the present research, the austenitic stainless steel grades of SS 304 and SS 202 and thickness of 2 mm and 1.2 mm respectively were CMT welded with SS 308 of 1.2 mm diameter filler wire. The CMT welding experimental setup is shown in fig. 1. Recent advancements in the modern industry have found many applications of tailor welded blanks (TWB) which are made from single sheets of steel of dissimilar thickness, coating, and, strength which are welded together[37]. Flexible part designs are allowed in this manufacturing procedure and it is ensured that the right amount of material is used in the right place. The shielding gas of 98% argon and 2% carbon mixture has been used for welding. During the process of welding, the shielding gas usually interacts with the filler metal which results in enhancement of mechanical as well as corrosion resistance properties of the weld deposits. An increase in CO₂ content % in the Argon + CO₂ mixture improves the wet ability of molten filler wire and fusion volume. It also leads to increased spatter rates and a decrease in the ferrite numbers [38]. The chemical composition of SS 202 sheet and SS 304 sheet is given in table 1 and table 2 respectively.

Table 1: Chemical Composition of SS 202

Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Al
73.9	0.103	0.490	10.5	0.0730	0.0179	12.8	0.303	0.205	<0.002

Table 2: Chemical Composition of SS 304

Fe	C	Si	Mn	P	S	Cr	Mo	Ni	N
71.9	0.0585	0.219	0.837	0.0426	0.0166	18.3	0.157	8.28	0.1

Figure 1: CMT Welding Experimental Set Up.

Figure 2: Welded Sample C7 at 115 A Current, 4 mm/s Welding Speed, 10% Arc Length Correction Factor.

Welding Parameters

A number of preliminary trial runs were conducted to set the welding parameters. The parameters are chosen in a way that the plates are welded correctly without any damage or burn through. The thickness ratio of the two plates is 1.67, which may result in local stress concentration and a shift in the neutral axis. The sheets are perfectly clamped in welding fixtures and necessary care has been taken to avoid distortion. Taguchi L9 orthogonal array has been applied here to optimize the welding parameters. Welding parameters such as welding current, welding speed and, arc length correction factor have been taken for welding of test specimens. Table 3 shows the process parameter values have taken for 3 different levels as per the L9 Taguchi technique. The shielding gas flow rate 15 L/min and contact tip to work-piece distance (CTWD) 10 mm is kept constant for all the samples. Fig.2 shows a sample welded at 115 A current, 4 mm/s welding speed and, a 10% arc length correction factor.

Table 3: Welding Process Parameters

Sample No.	I (A)	W.S (mm/s)	A.C.F (%)	CTWD (mm)
C1	75	4	-10	10
C2	75	5	0	10
C3	75	6	10	10
C4	95	4	0	10
C5	95	5	10	10
C6	95	6	-10	10
C7	115	4	10	10
C8	115	5	-10	10
C9	115	6	0	10
I = Current, W.S = Welding Speed, A.C.F = Arc Correction Factor, Flow Rate Of Shielding Gas = 15 Ltr/Min				

RESULTS AND DISCUSSIONS

Tensile Test (UTM)

The welded specimen for the tensile strength testing was cut as per ASTM E8 standard using wire EDM process. The size of the tensile test specimen is shown in fig. 3. The tensile specimens before and post testing are shown in fig. 4 and fig. 5 respectively. TINIUS OLSEN H50KS tensile testing machine capacity of 50 KN was used to investigate the tensile properties of the weld specimens. The strain rate of 1 mm per min at room temperature is fixed for tensile testing.

Figure 3: Tensile Testing Specimen as per ASTM E8 std.

Figure 4: Tensile Specimens Before Testing.

Figure 5: Specimens Post Tensile Test.

Welding entails the melting and solidification of the base metal. Welding of dissimilar materials involves fusion of two different materials having different solidification rate. This ultimately changes the microstructure and the grain size. The weld zone bead has high strength due to the alloy genesis. The filler wire along with the melted base metal forms this alloy thus making it the strongest portion. The typical tensile stress-strain graph of welded samples (C1, C4, C5, C7, C8) is shown in fig. 6. The tensile strength and elongation results obtained for the welded sample are shown in table 4. The maximum tensile strength achieved is 291 MPa at 115 A current, 4 mm/s welding speed, and 10 % arc length correction factor. The tensile results show an increase in weld strength as the welding current is increased and no significant change in the elongation was observed. Prakash et al. (2017) [39], reported that sample SS202-SS316 of 1.5 mm sheets spot welded

specimen tensile strength was 268 MPa. In this study, the maximum tensile strength value of 291MPa was achieved. This strength was achieved at 4 mm/s welding speed and 10 %arc length correction factor. Arc length is the distance between the end of the filler wire and workpiece material. An arc length correction factor is also an important process parameter to determine and maximize the tensile strength of welded material. A positive arc length provides better strength and perfect penetration. Kannan et.al. (2019) [40] results support for a significant increase in strength for samples C1, C5 and, C7 with positive arc length correction factor. It was observed that the maximum elongation observed with a higher positive arc length correction factor welded sample.

Table 4: Tensile Properties

Sample No.	C1	C2	C3	C4	C5	C6	C7	C8	C9
Tensile Strength(MPa)	274	270	272	275	284	276	291	289	278
Elongation (%)	18.3	19.2	20.4	22.4	23.4	21.3	23.3	22.8	21.7

Figure 6: Typical Stress vs Strain Graph of Welded Specimen.

The tensile fracture of the welded specimen clearly shows the formation of a cup-cone shape when necking initiates or due to surface slip occurs. Joining dissimilar material thickness leads to uneven heat distribution and a higher amount of heating takes place in thicker sheets in comparison with smaller thickness sheets. These results lead to maximum penetration in the thicker plate and less take place in thin sheets [41]. Marashiet. al.(2008) [42] observed that in spot welding of dissimilar thickness material's necking initiated in lower thickness sheets. The thinner sheets occur severe necking due to lesser force. The finite element results have shown the concentration of stress in the thinner section due to plastic distortion in the thinner part [43]. The efficiency of the welded joint was 100 % as all the failures occurred in the heat-affected zones (HAZ) of the thinner section of the SS 202 material. These results revealed that evidence of low heat input characteristics of CMT welding provides higher strength joints for dissimilar thickness.

Micro-Hardness (HV)

Figure 7: Micro-Hardness Variation for Sample C7 Welded at 115 A Current, 4 mm/s Welding Speed, 10% Arc Length Correction Factor.

Fig.7 shows the micro-hardness variations for the welded sample C7 welded at 115 A current, 4 mm/s welding speed, and 10 % arc length correction factor with respect to the positions. The higher hardness value was observed on the welded region and decreasing trend in the base metal (BM) and heat-affected zone (HAZ) for both the steel sheets. The micro-hardness of base material SS 202 and SS 304 are 325 HV and 280 HV respectively. The hardness in the material depends upon the carbon content and it controls the presence of cementite. The carbon content in SS 202 is slightly higher than SS 304 thus a difference in the hardness value of the base metal is observed. The micro- hardness of both SS 202 and SS 304 in the heat-affected zone (HAZ) reduces to 290 HV and 270 HV respectively. Sabooniet. al (2015) [44] reported that Friction stir welding of SS304 softening of HAZ takes place due to the recovery of coarser grains. According to the hall-petch relationship, the hardness and strength of a material are correlated to grain size. The reduction of micro-hardness in HAZ due to coarser grains. The hardness of the material relates to tensile properties in a material. The low hardness in HAZ is an important factor for the initiation of crack and fracture took place in this region during the tensile testing. Hardness is increasing towards the weld region. The increasing trend between HAZ and WZ is due to enhanced refinement grains of the austenitic steels. Similar type of pattern reported in the welding of SS 202 and SS 304 by TIG welding [45]. The hardness value achieved by CMT welding is higher than TIG welding. The hardness value of material depends upon the heat input that occurs during welding. Lesser heat input results in harder increases in weld region. The diffusion of chromium element between the two stainless steel sheets increases the hardness of weld zone. The highest micro-hardness value at the weld zone was 480 HV achieved for the C7 sample which is welded at the highest current value (115 A), slow welding speed (4 mm/s) and a positive arc length correction factor (10 %). The micro-hardness value in the welded region in the range of 460-480 HV due to its finer grain structure and excellent fusion of filler wire in the weld zone. Besides that the high rate of cooling in CMT process and an incomplete austenitic transformation in weld zone forms delta-ferrite phase. These are reasons for increasing the hardness in the welded region. Fig. 8 shows similar types of results for samples C1, C4, C5, and C8.

Figure 8: Micro-Hardness Variation with the Distance from the Weld.

Residual Stress (MPa)

Residual stresses are the stresses that are present within a body or a material after the process of manufacturing and material processing in the absence of temperature gradients or external loads [46]. These stresses which are produced due to non-uniform distribution of temperature are measured by PULSTEC micro-X360n Full 2D X-ray residual stress analyzer, which operates on X-ray diffraction technique. It is associated with cos alpha method that uses a single exposure to collect the entire diffraction cone via a 2D detector. This system consisted of a sensor unit attached to a computer for output result and a power system. The sensor unit uses cos alpha method to calculate the residual stress. Amongst the number of available non-destructive techniques for measuring the residual stresses, X-ray diffraction is suitable for thin plates as its penetration is about $10\mu\text{m}$ with spatial resolution in the range of $10\mu\text{m}$ to 1mm , thus suitable for thin stainless steel plates. Some positions were marked comprising of the base metal plate (BM), heat affected zone (HAZ) and the weld zone (WZ) on both plates. Full debye-scherrer ring at each position was acquired through X-ray exposure. These rings determined the strain and finally the residual stress value at each position was produced [47].

Figure 9: Residual Stress Points at Sample C7.

Figure 10: Position 3 (Sample C7) under X-Ray Diffractor.

Figure 11: Residual Stress Variation at Different Zones of Sample C7 Welded at 115 A, 4 mm/s Welding Speed and 10 % Arc Length Correction Factor.

Residual stresses were taken at different points which are shown in Fig 9. X-ray diffractor position 3 is shown in Fig. 10. Standard chromium (Cr) material X-ray tube is used having collimator size of 1mm diameter with 30kV and 1mA specification for determining these stresses. The achieved residual stress values for the C7 welded sample for different regions are as shown in the graph in fig.11. Compressive residual stress was produced in the base plate and weld zone. Tensile residual stress was produced in the heat affected zone (HAZ). During the process of joining by CMT process, due to low heat input, upper and the lower weld zone surfaces experiences a higher rate of solidification due to rapid cooling than the material within the weld pool and the heat-affected zone (HAZ). This uneven rate of cooling leads to differential thermal distribution thus causing expansion in the heat affected zones and contraction in the weld zone. Due to this, the residual stress in the weld zone tends to become negative (compressive) due to shrinkage of the grain size (fine grains). The compressive stress in a way is desirable as it helps in avoiding the formation of cracks and notches. Relief from stress corrosion cracking also observed in the weld region. The slow cooling and coarser grains in the heat-affected zone (HAZ) results in a positive or tensile residual stress. This tensile residual stress present in the heat-affected zone is detrimental and results in fatigue failure. There may be chances of crack initiation and thus material fails most of the time in this region

which leads to degradation of mechanical properties. The plots obtained in fig. 12 for samples C1, C4, C5, C7, C8 between SS 304 and SS 202 was nearly the mirror images of each other. A similar type of results was observed in all the samples.

Figure 12: Residual Stress Variation at Different Zones of Welded Samples.

CONCLUSIONS

The paper investigates the mechanical characteristics of welded joints of dissimilar austenitic steels SS202 and SS304 thin sheets by cold metal transfer welding technique. The below mentioned are the conclusions drawn from this experimental study:-

- CMT welding is a suitable technique for welding thin stainless steel plates of dissimilar grades and different thicknesses.
- A tailor welded blank of blank ratio 1.67 can be made of stainless steel sheets of grades SS 304 and SS 202 with optimum strength and hardness.
- The highest strength equal to 291 MPa and highest hardness equal to 480 HV is achieved at 115 A current, 4 mm/s welding speed, and 10 % arc length correction factor.
- Low heat input and rapid cooling in CMT welding results in compressive (negative) residual stress in the weld zone making it the strongest and hardest zone.
- The HAZ is the most affected portion of the joint due to coarser grains and tensile residual stress because of the slow cooling here thus making it a hotspot for failure. The necking starts in the thinner section and results in cup-cone shaped fracture.

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