International Journal of Engineering & Technology, 7 (3.17) (2018) 215-218

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Welding of Dissimilar Steels via Thixowelding Processes

M. N. Mohammed[1*], M. Z. Omar[2], K. S. Alhawari[2], M. A. Abdelgnei[2] and Salah Al-Zubaidi[3]

[1]Department of Engineering & Technology, Faculty of Information Sciences and Engineering
Management & Science University, 40100 Shah Alam, Malaysia
[2]Centre for Materials Engineering and Smart Manufacturing (MERCU)
Faculty of Engineering and Built Environment
Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia
[3] Department of Automated Manufacturing Engineering, Al-Khwarizmi college of Engineering,
University of Baghdad, Baghdad 10071, Iraq
** Corresponding author E-mail: mohammed@msu.edu.my*

Abstract

In several circumstances, traditional welding processes cannot produce sound weldments especially for high grade materials. In this research, a dissimilar joint of AISI D2-AISI 304 steels was produced by using new semi-solid joining process. The achieved findings revealed the quality of dissimilar joints compared with other welding processes. During Metallographic investigation, neither oxides nor micro-cracks were observed along the interface of semi-solid joint. This study confirmed that the development of dendritic structure was avoided and high quality joint can be obtained.

Keywords: *Thixojoining, Semi-solid metal joining (SSMJ), Thixowelding, Direct partial remelting (DPRM).*

1. Introduction

The material joining is one of the major activities in the industry and assembly process. Fusion welding is one of the most commonly used conventional joining techniques. Unfortunately, fusion welding is known by high temperature gradients that lead to high thermal stress and rapid solidification, which gives rise to the occurrence of segregation phenomenon. Also, the morphology of the welded interface is typically dendritic and the natural progression of solidification frequently leads to internal structural defects, such as shrinkage porosities and loss of alloying elements, resulting in a nonhomogenous microstructure [1], as shown in Figure-1. Therefore, an innovative process that is able to overcome the abovementioned limitations associated with fusion welding is desired. One solution that has good potential is thixojoining, which is free from the above problems where the solidification and heat transfer processes largely differ from those of typical welding methods [2].

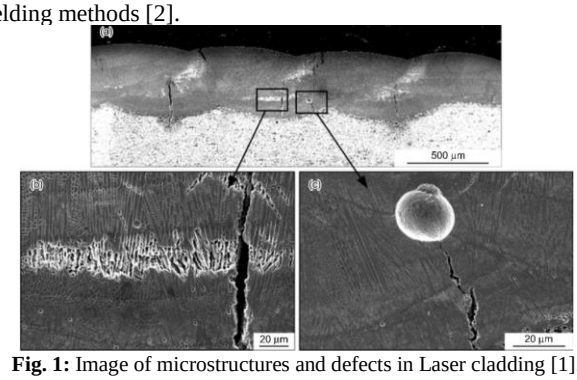


Fig. 1: Image of microstructures and defects in Laser cladding [1].

Following the Spencer et al. work (1972), which distinguished and identified the basic thixotropic behaviour [3,4], many different semisolid metal (SSM) processing or thixoforming techniques were developed to utilize the characteristic advantages of these properties [5,6]. This then led to other joining processes and techniques being developed called "semisolid metal joining (SSMJ)" or "thixojoining" based on the principles of SSM processing, which occurred when the alloy is heated to mushy zone between the solidus and liquidus temperatures, that is, when the material shows thixotropic behaviour [7,8]. Metals in a thixotropic state have many useful properties that allow them to be joined more easily, such as (1) moderate softness, (2) excellent workability, (3) good flowability, (4) flexible geometrical adaptability, and (5) active chemical and metallurgical join ability. As a result, it is easy to embed items into metals processed in this way, many kinds of solid materials can be used, and joining conditions are relatively good [9]. However, one of the most important and useful characteristics of semisolid alloys is their so-called "joinability." As it is well known, semisolid alloys consist of two components: solid & liquid. The former component is in nature very active in diffusion compared with the solid one and due to this activity, the semi-solid alloys have characterised by good weldability compared with other materials [10, 11]. Hence, the SSMJ process has the potential to transform the production of metal components. The first investigation work in the 1990s has already expounded the process feasibility, but it also revealed several technical problems that need to be overcome [12]. However, this research area has not get enough consideration and focus by investigators, so the process is still in early stage and under development. This work is concerned with semi-solid joining of dissimilar steels parts. Direct partial-remelting technique (DPRM) is adopted to produce thixo-weld joints. The main objective of this study is to produce welds with globular structure during thixo-joining process.

Copyright © 2018 Authors. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

2. Experimental Procedure and Materials

The AISI D2 cold-work tool steel is the alloy that was used in this study as base blank and its as received condition is soft annealed by heating to 850°C and cooled with a rate of 10°C/h to 650°C and then air cooled. AISI 304 stainless steel is the second used alloy as insert in this work to accomplish the SSJP of dissimilar materials. Table 1 shows their chemical compositions as determined X-ray fluorescence technique (XRF).

Table 1: Chemical composition (wt %) of D2 and 304 steels

Element	AISI D2	AISI 304
C	1.55	0.06
Si	0.258	0.438
Mn	0.239	1.436
P	0.025	0.030
S	0.01	0.023
Cr	11.2	18.31
Ni	0.197	8.182
Mo	0.79	0.215
V	0.85	
W	0.2	
Cu	0.08	0.436
Fe	Balance	Balance

The temperatures of solidus and liquids for both alloys were determined by using the Differential scanning calorimetry analysis (DSC). The supplied materials were cut into tiny pieces with less than 20 mg and examined by using a simultaneous thermogravimeter type Netzsch-STA-449-F3 (TGADSC). 10ºC/min was selected as heating rate and the test done in nitrogen environment for protection during heating of samples up to 1500°C. The baseline for calculating the liquid fraction was constructed using a 'common tangent' procedure. At the beginning, the base metals of the two steels (i.e. AISI D2& 304) was cut in samples with dimensions of Ø16×100mm and Ø7×18mm respectively. Later on, every sample was immersed for 5 min in pickling solution (60ml H_2O plus 40ml HCL (37%) for descaling, rust removing, and obtaining clean surface of the metals. Finally, all samples were washed using acetone, rinsed carefully by distilled water and dried well in air. Careful grinding and polishing were done for all samples after performing experiments of direct partial remelting technique to get surface with mirror outlook. The Villela solution was used to etch all samples to explore their microstructures. The joint interfacial microstructures have been captured by using optical and scanning electron microscopes provide with an EDX analysis while phases identification was done by X-ray diffraction analysis (XRD) was performed to identify the phase evolution. The most significant solid-state route that can produce globular structure is direct partial remelting (DPRM) is considered one of the most effective solid state routes to produce a non-dendritic microstructure predominately of high melting alloys when heating to mushy zone [8-9]. A high temperature vertical carbolated furnace was selected to carry out the experiments of DPRM. The furnace environment is protected by argon gas. Once the pre-determined temperature of 1300 °C is reached the sample of base and insert is dropped down by chromel wire to the hottest zone in the furnace and kept there for 10 min, then air cooled.

3. Results and Discussion

3.1. Microstructure and joint quality

According to the graphs in Figure-2 and Figure-3, the liquid fractions at 1300°C of AISI D2 and AISI 304 steels are 25 and 0% respectively. Therefore, there is a big gap in liquid fractions between the two types of steels for AISI D2 was around 25% while for AISI 304 stainless steel at the same predefined temperature.

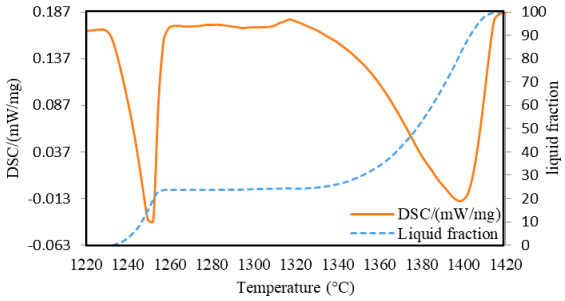


Fig. 2: DSC heating flow and liquid fraction curve for AISI D2.

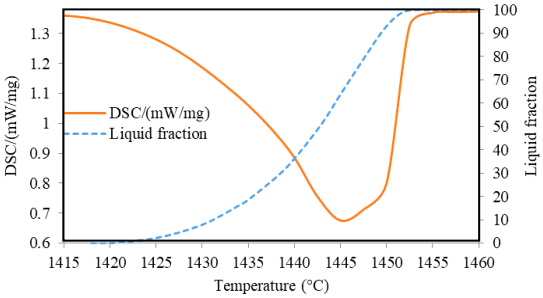


Fig.3: DSC heating flow and liquid fraction curve for AISI 304.

Figure 4 shows the microstructure of thixo-weld joint that was captured by optical microscope. From the complete cross-section of the weld at 1300°C applied heating temperature, it can be seen that a good joints could be obtained. It can be noticed the full penetration of the welded joint, and remarking of various colours in the same grain at the diffusion region. Moreover, the grains of base metal were subjected to the formation and growth of new columnar crystals near the diffusion zone during semi-solid operation as shown in Figure-4. Non-equilibrium diffusion has occurred as a result of variety in chemical compositions and liquid fractions between the two types of steels.

With respect to the interfacial structure, both alloys show distinctive response and diffusion capabilities where base alloy is joined perfectly to the insert along the bonding circumference of the interface. This is due to the formation of higher amounts of interfacial reaction products between the two base steels [13, 14]. No evidence of detection porosity or micro-cracking at the transition zone, and the joint texture appeared non-corrugated and smooth as shown in Figure-5. The full penetration of the welded joint was noticeable and promoted the perfect joining at the alloys interface where the base blank is joined to the insert along the boundary.

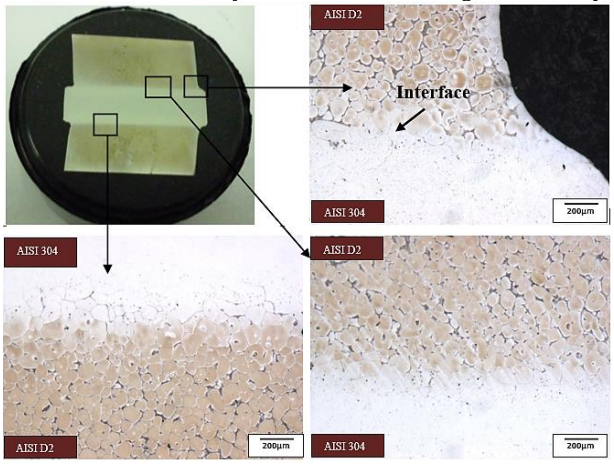


Fig. 4: Optical microstructure of the thixojoined parts of the three samples produced under different process parameters.

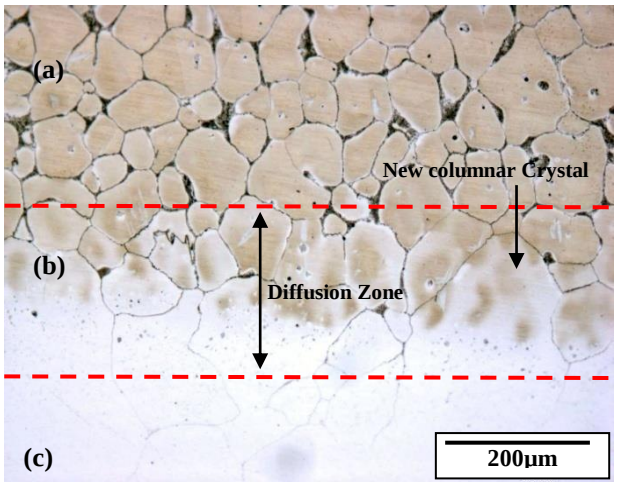


Fig. 5: Microstructure of thixo-weld joint of (a) AISI D2 base, (b) diffusion region and(c) AISI 304 stainless steel insert after DPRM at 1300°C for 10 min.

3.2. Microstructure characterization and phase identification

During the joining of AISI D2 with dissimilar metals, a new region may exist near the contact area that exhibit differences in the chemical compositions, microstructures, and properties derived from the base blank and insert pin. A different region was realized in the microstructure of joints near the transition region in the AISI D2/AISI 304 in the present research.

Scanning electron microscopy combined with EDX analysis was performed to scrutinize the developed phases that precipitated during the thixo-joining process at the interface region. The EDX analysis with SEM structure is shown in figure 6 the points 1,2, and 3 refer to the base (AISI D2), diffusion zone, and the insert (AISI 304) of the thixo-weld joint respectively The findings of EDS analysis emphasize the creation of aggregated compounds from the two different alloys. The variety of compositional between the base and insert has participated and increased the tendency towards the precipitation of such that compounds at the interface area [2, 15]. In addition, EDX line scan analysis was also performed along the marked line to estimate the chemical compositions near the diffusion region of thixo-weld joint, as depicted in Figure-7. The substitution of the atoms in the lattice should be considered in identifying phase composition. From Figure-7 it is observed that the Ni and Cr elements were immigrated towards AISI D2 side while AISI 304 has picked up the Fe and C from D2 tool steel side.

Three phases can be distinguished from the pattern of X-ray diffraction of figure 8, namely: α ferrite, γ austenite, and M_7C_3 carbides respectively. There are no brittle or harmful phases were identified. The observations showed that the diffusion rate that has occurred and depth of penetration of diffused elements from D2 tool steel towards 304 stainless steel is higher and this is agreed well with the metallographic examination.

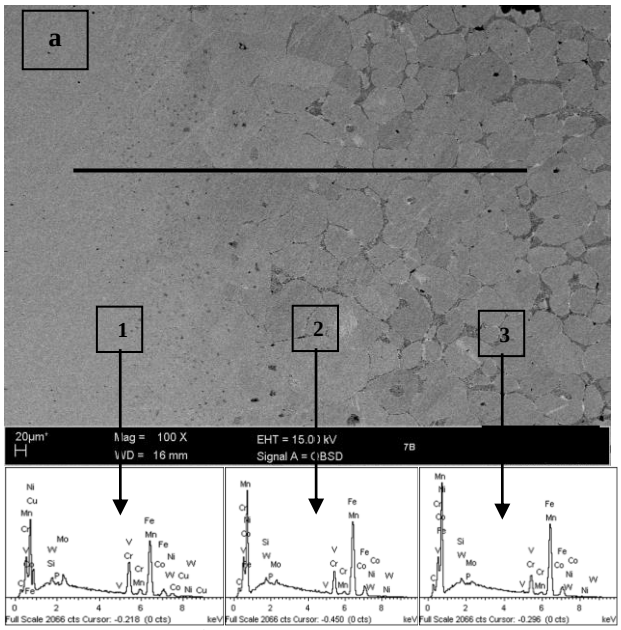


Fig. 6: SEM image of thixo-weld joint at 1300°C with EDX analysis at points (1) for AISI 304, (2) for diffusion zone and (3) for AISI D2.

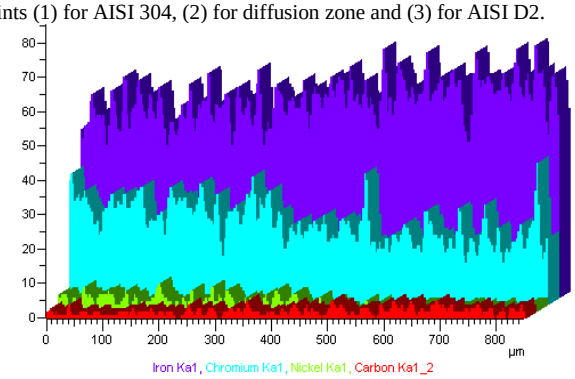


Fig. 7: Distribution of elements along the joint centre of Fig. 6.

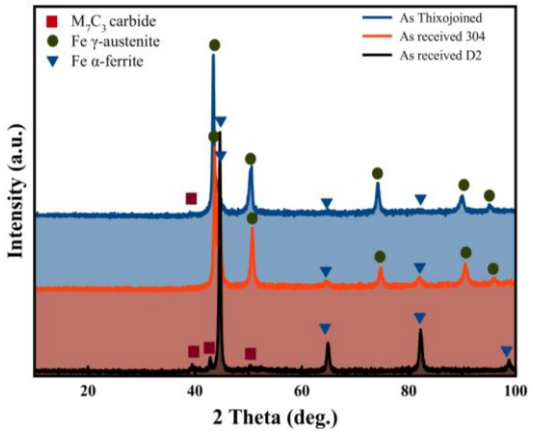


Fig. 8: the pattern of X-ray diffraction pattern for as-received AISI D2 and AISI 304 along the joint centre

4. Conclusions

A new Semi-solid metal joining (SSMJ) process of D2 cold work tool steel with 304 stainless steel using direct partial re-melting technique has been investigated through this research. According to the findings of the conducted experiments, the SSMJ process has approved its ability in producing good joint with fine interfacial diffusions around the circumference boundary of D2 blank and 304 insert. Further, the transition from one alloy to other was smoothly by creation and growth new columnar crystals at the diffusion zone. Neither micro cracking nor porosities were observed at the transition zone. Moreover, by adopting this kind of

welding process, mechanical force or complicated apparatuses are not required contrasted with traditional joining processes. Based on the conducted study, it can be said that various pairs of steels can be safely thixo-welded.

References

[1] Pleterski M, Tuˇsek J, Muhic T & Kosec L (2011), Laser Cladding of Cold-Work Tool Steel by Pulse Shaping, J. *Mater. Sci. Technol.* 27(8), 707-713.

[2] Mohammed MN, Omar MZ, Salleh MS & Alhawari KS (2013), Study on Thixojoining Process using Partial Remelting Method. *Journal Advances in Materials Science and Engineering* 10.1155/2013/251472.

[3] Spencer DB, Mehrabian R & Flemings MC (1972), Rheological behavior of Sn-15 Pct Pb in the crystallization range. *Metallurgical and Materials Transactions* 3:1925-1932.

[4] Mohammed MN, Omar MZ, Salleh MS, Alhawari KS & Kapranos P (2013), Semi-solid metal processing techniques for nondendritic feedstock production. *The Scientific World Journal* doi:10.1155/2013/752175.

[5] Alhawari KS, Omar MZ, Ghazali MJ, Salleh, MS & Mohammed MN (2017), Microstructural evolution during semisolid processing of Al–Si–Cu alloy with different Mg contents. *Transactions of Nonferrous Metals Society of China* Volume 27, Issue 7, Pages 1483-1497.

[6] Mohammed MN, Omar MZ, Syarif J, Sajuri Z, Salleh MS & Alhawari KS (2013), Microstructural Evolution during DPRM Process of Semisolid Ledeburitic D2 Tool Steel. *The Scientific World Journal* doi:10.1155/2013/828926.

[7] Mohammed MN, Omar MZ & Salleh MS (2014), Morphological Evolution during Partial Re-Melting of AISI D2 Cold-Work Tool Steel. *Sains Malaysiana* 43(8) 1213-1219.

[8] Alhawari KS, Omar MZ, Ghazali MJ, Salleh MS & Mohammed MN (2015), Evaluation of the microstructure and dry sliding wear behaviour of thixoformed A319 aluminium alloy. *Materials & Design* 76 169–180.

[9] Kiuchi M & Kopp R (2002), Mushy / Semi-Solid Metal Forming Technology - Present and Future. CIRP Annals - *Manufacturing Technology* 51: 653–670.

[10] Mohammed MN, Omar MZ, Syarif J, Sajuri Z, Salleh MS & Alhawari KS (2015), Semi-Solid Joining Of D2 Cold-Work Tool Steel. *Solid State Phenomena* 217-218, 355-360.

[11] Mendez PF, Rice CS & Brown SB (2002), Joining using semisolid metals. *Welding Journal* 81: 181−187.

[12] Mohammed MN, Omar MZ, Sajuri Z, Salleh MS & Alhawari KS (2015), Trend and Development of Semisolid Metal Joining Processing. *Advances in Materials Science and Engineering* vol. 2015, Article ID 846138, 13 pages, 2015. doi:10.1155/2015/846138

[13] Vigraman T, Narayanasamy R & Ravindran D (2012), Microstructure and mechanical property evaluation of diffusion-bonded joints made between SAE 2205 steel and AISI 1035 steel. *Materials & Design* 35, 156–169.

[14] Omar MZ, Atkinson H & Kopranos P (2007), Semi-solid metal processing - a processing method under low flow loads. *Jurnal Kejuruteraan* 19. pp. 137-146

[15] Mohammed M. N., Omar M. Z., Zubaidi S., Alhawari K. S., Abdelgnei M. A., (2018), Microstructure and Mechanical Properties of Thixowelded AISI D2 Tool Steel. Metals.; 8(5):316.