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Effect of Heat Input on Microstructural and Mechanical Properties of AISI 304 Welded Joint Via MIG Welding

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ABSTRACT

In this experimental work, AISI 304 was welded via metal inert gas (MIG) welding process with Argon (Ar) as shielding gas. In the present study, AISI 304 was subjected to different heat input using a standard 308L electrode. Weld quality i.e. ultimate tensile strength, toughness, microhardness, and microstructure of AISI 304 were examined. Microstructures of welded joints were studied using scanning electron microscopy (SEM), linked to the SEM was used to determine the chemical composition of phases formed at the joint interface and from the result, it was revealed that at low heat input ultimate tensile strength is higher than those at medium and low heat input. From the result, it was also observed that grain coarsening extent in the HAZ increases with an increase in the heat input. It was also found that the fractures of toughness samples were brittle in nature which shows the low ductility and brittle fracture. Weld zone microstructure exhibited skeletal δ-ferrite in austenite matrix with various ferrite contents. Microhardness of weld bead was found to decrease with increases in the heat input. It was also observed that at medium heat input there was an improvement in tensile strength, elongation, and hardness due to finer grain structure and smaller inter-dendritic spacing.

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NOMENCLATURE

HI	Heat input	ASS	Austenatic stainless steel
MIG	Metal inert gas	UTS	Ultimate tensile strength
V	Arc voltage	HAZ	Heat effected zone
I	Welding current	SEM	Scaning electron miroscope
S	Welding speed	TIG	Tungsten inert gas
AISI	Aremican Iron and steel institute	ASS	Austenatic stainless steel

1. INTRODUCTION

Manufacturing industries including automotive, railway, aerospace, shipbuilding, and petrochemical develop products ranging from simple to big in complex shapes. Conventionally, stainless steels are joined by metal inert gas welding, tungsten inert gas welding, friction stir welding etc. In MIG welding, the common variations of power supplies, shielding gases, and copper coated wire have significant effects resulting in a number of different and important process parameters [1]. MIG welding frequently accepted globally due to high productivity rate and spatter free quality [2]. AISI 304 is frequently used in structural industries for fabrication purpose as it is more economical and anti corrosion-resisting steels as compared to other steels. Stainless-steel sheets are increasingly used for boiler, vessels, pharmactical, aerospace, thermal power plant, kitchen, building, transportation, etc., because of their high corrosion resistivity, beautiful appearance, superior strength, toughness and low temperature toughness [3-5]. AISI 304 can be welded with several welding process such as MIG, TIG, friction, laser beam welding etc. Extensive stidies were carried out on the effect of heat input [6, 7] on the microstructure and mechanical properties of AISI 304 (Austenitic stainless steel). Hsieh et al. [8] reported that shielding gas using for welding

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purpose significantly promote the depth/width ratio of welded joint of SS204H by TIG welding whereas silicon and phosphorus have a least significant effect on the depth/width ratio. Saluja and Moeed [9] studied the effect of pulse-GMA welding process parameters on the hardness of AISI 304 steel and they reported in their result that cooling rate and alloying elements significantly vary micro-hardness. Heat input also play an important role in grain size of a weldment and grain size of the weldments increases with the increasing in the heat input [10]. Moradi et al. [11] developed a mathematical model to study the parameter dependencies in laser hybrid arc welding of high strength steel by design-of-experiment (DOE) and mass balance. Moradi et al. [12] studied the numerical and experimental geometrical dimensions on laser-TIG hybrid welding of stainless steel 1.4418. Khorram et al. [13] investigated the effect of linear haet input on bead geometery, microstructure and mechanical properties of Ti-6Al-4V sheet welded by CO_2 laser welding and it was observed from result that on increasing the linear heat input caused to change the martensistic phase from an acicular ferrite. The novelty of this research work is to investigate the effect of heat input on microstructure and mechanical properties of AISI 304 ASS on different heat input i.e. on six different values of heat input. it is also observed from previous studies that six different values of heat input were not considered.

2. EXPERIMENTAL DETAILS

2. 1. Work Piece Material

AISI 304 is one of the most commonly used materials in manufacturing industries because it has better corrosion resistance and good weldability [14]. The parent metal used in this study was AISI 304 (ASS) in the plate form of 150x60x6 mm^3 size and welded by Metal inert gas (MIG) welding, with polarity of direct current electrode negative (DCEN) with ER308 electrode. Chemical composition of base metal, filler wire, mechanical properties, and MIG welding parameters of AISI 304 (ASS) are provided in Tables 1, 2 and 3, respectively. The actual welding set used in this process is shown in Figure 1.

For shielding purpose pure Agron (Ar) gas was used. Butt joints were successfully prepared in this study using selected welding process parameters and tensile test samples and toughness test samples were prepared as per ASTM. All essential care was considered during the welding process to avoid joints distortion by using proper clamping arrangement. Six weld coupons of various heat input with nealry equal interavls were sellected for investigation purpose. Welding parameters and samples designation are listed in Table 4.

TABLE 1. Chemical composition of parent metal and filler wire

Material	% of C	% of Cr	% of Ni	% of S	% of Mn	% of P	% of Si	Fe
Type AISI 304	0.065	18-20	8-10.5	0.015	1.25	0.025	0.48	Rest
Filler wire ER 308	0.035	18.5	8.5	0.04	1.55	0.02	---	

TABLE 2. Mechanical properties of base metal

Material	YS (MPa)	UTS (MPa)	% Elongation	Toughness (J)	Hardness (HV)
AISI 304	315	650	50	105	90

TABLE 3. Parameters used for MIG welding process to obtain various heat input condition

Welding current (A)	Arc Voltage (V)	Shielding gas flow rate (l/min)	Wire feed speed (IPM)
200	20	10	250

Figure 1. Actual set up for MIG welding

TABLE 4. Parameters used for MIG welding process to obtain various heat input condition

Sample No	Welding current (A)	Arc voltage (V)	Welding speed (mm/s)	Heat input (Kj/mm)
G2	160	20	1.464	2.18
G4	170	21	2.86	1.25
G10	175	22	1.411	2.73
G12	180	23	1.39	2.97
G15	188	24	1.38	3.27
G16	195	25	1.38	3.52

Welding heat input (HI) is defined as the product of arc voltage (V) and welding current (I) divided by welding speed (S) and methamatically is expressed as follows:

$$Q_{arc} = 60 \times V \times I/(S) \quad (1)$$

where V is the arc voltage (V), I is the arc current (A) and S is the welding speed in mm/min.

3. RESULT AND DISCUSSION

3. 1. Mechanical Properties For weld quality purpose, mechanical properties like ultimate tensile test, toughness test, and microhardness test were carried out. Tensile strength of a welded joint is too much influence in grain size of weldment [15]. Figure 2 shows the geometrical sketch of a tensile test sample used in this study and tensile test sample and toughness samples were fabricated as per ASTM. Effect of welding heat input on tensile strength and toughness of welded joints were investigated at different heat input and for each condition of heat input, three samples were conducted for tensile test and toughness test and the average value was recorded and presented in Figure 3. From Figure 3 it is very clear that at only 1.25 kJ/mm (low heat input) UTS and toughness increases while on increasing the heat input tensile strength (UTS) and toughness of weldment decreases [16]. It is only due to increasing the arc voltage and formation of δ-ferrite grains in the weld region.

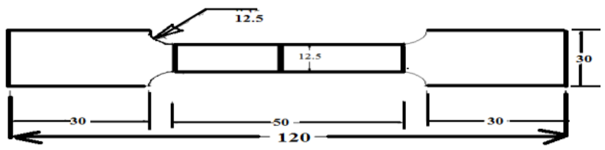


Figure 2. Geometrical sketch of a tensile test sample

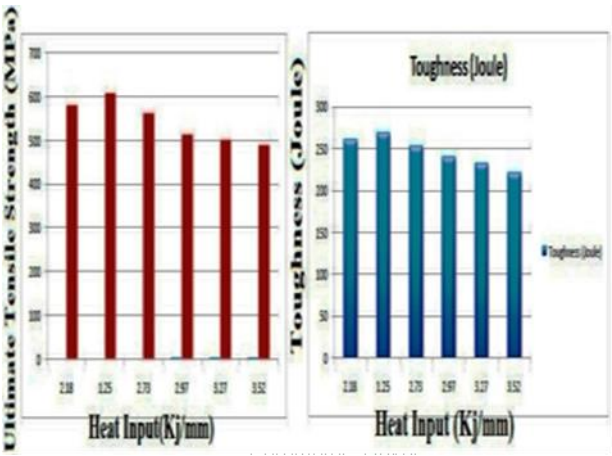


Figure 3. Effect of Parameters on Mechanical properties

3. 2. Microhardness Microhardness (HV) of various zones of weldments was measured by VHN testing machine. Figure 4 presents the microhardness of weldments at different heat input at different zones i.e. base metal zone (BM), heat affected zone (HAZ), and weld zone (WZ) or fusion zone measured in the longitudinal direction and the trends of curves are like "M" world which is very common and heat input influence the hardness of welded joint. It can be seen that the hardness distribution of weldments were similar, so taking heat input 2.73kJ/mm as an example to exhibit the microhardness variation in above-said each zone of weldments. From Figure 4 it is very clear that the hardness of weld zone is lower than HAZ, and parent metal zone (PM) [17]. Increasing in hardness is only due to the larger contents of δ-ferrite in the weld zone and finer grain size in the HAZ by increasing heat input [18]. From the previous research it is very clear that the presence of δ-ferrite in the weldment enhance the mechanical properties [19]. Hardness in HAZ is still higher than the parent metal (PM), this is only due to rapid cooling of weldment leads to refinement of the grains. On increasing the heat input overall value of hardness of weldment decreases; this is only due to lower the δ–ferrite contents lead to lowering the hardness value [20].

3. 3. Fractrography SEM fractogrph of toughness test samples at different heat inputs of various zone i.e. parent metal zone, HAZ, and weld zone (WZ) are shown in Figure 5. Figure 5 (a) shows the ductile fracture mode with several numbers of voids. It is due to different cooling rate. Brittle fracture is formed in fusion zone with dimple formed on the tearing ridges. High heat input requires more time to solidification hence responsible to produce the coarse or large dimple [21] as shown in Figure 5(c).

3. 4. Microstracture Microstructure examination of welded joints under different heat inputs values has been carried out by optical microscope and fartrography of toughness samples were studied by SEM. Weld zone

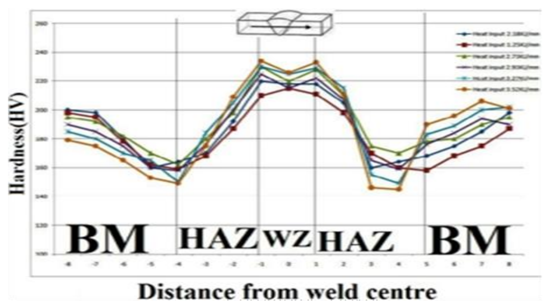


Figure 4. Microhardness (HV) profile at different heat input indicating hardness on weldment at various zones

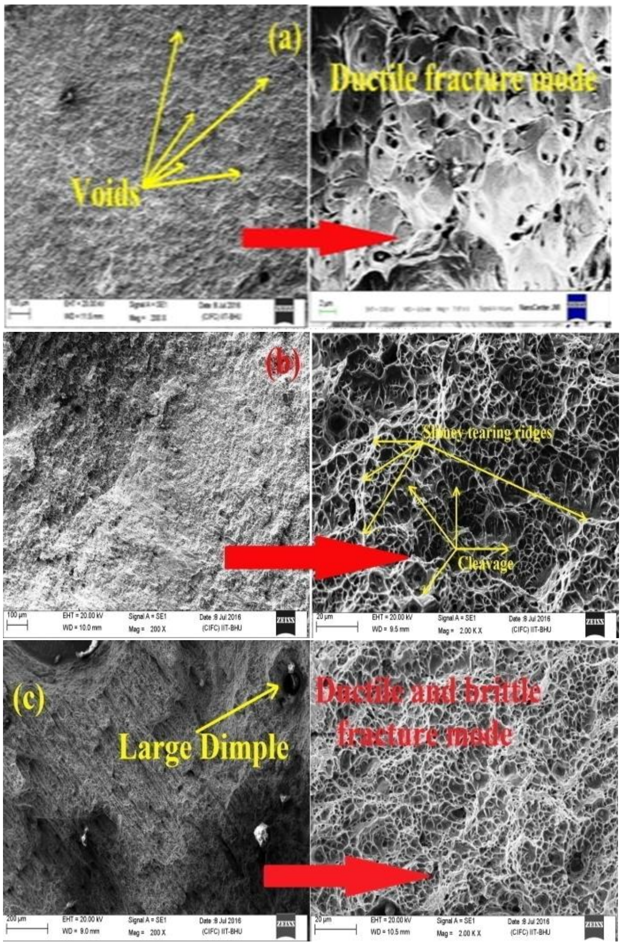
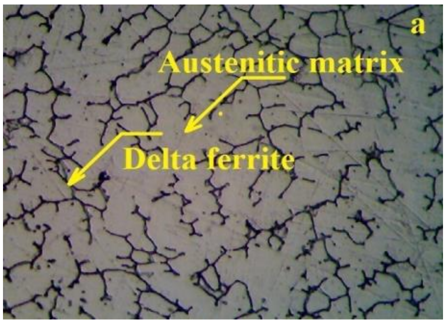
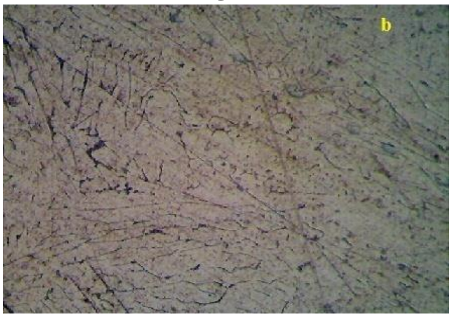


Figure 5. Macro image and SEM fracture of Toughness fracture surface of Base metal, HAZ, and Weld zone

attained the maximum temperature, which is just below the solidus temperature. Microstructures of welded joints are given below at different heat input. From Figure 6 it was observed that microstrucute of AISI 304 welments containing two micro-constituents, namely δ-ferrite (dark) and austenite (light). Figure 6 shows the variation of δ-ferrite morphology in the different zone and it is also observed from Figure 5 that three different kinds of δ-ferrite i.e. δ-ferrite, lathy, and skeletal ferrite (in weld zone has a wider spacing) are formed in the austenite matrix [22]. Figure 6 (b) G4 samples at low heat input leads to formation of finer dendrite size it is due to slow cooling [23, 24]. Figure 6 (d) sample G12 shows the fusion zone and fusion area increased with increase in heat input. Microstructure of weldments is significantly influence by heat input as voltage is a function of heat input [25]. From literature reviews it is very clear that heat input having major effect on microstructure of AISI 304 weldment [26, 27].

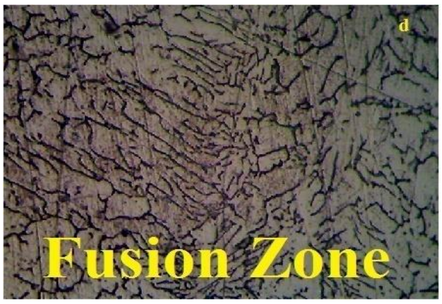


G2

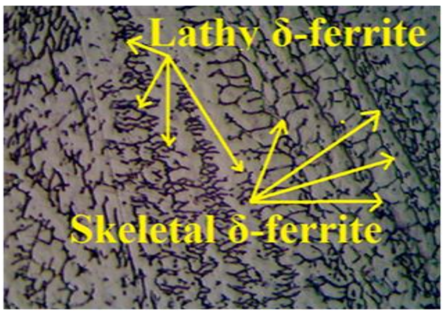


G10

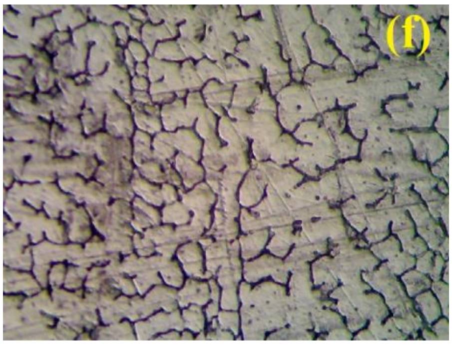
G4



G15



G12



G16

Figure 6. Optical microstructures of the welded samples under pure Ar shielding with different heat input: weld metal structure welded at (a) 2.18 kJ/mm, (b) 1.25 kJ/mm, (c) 2.73 kJ/mm, (d) 2.97 kJ/mm, (e) 3.27 kJ/mm, and (f) 3.52 kJ/mm

4. CONCLUSSION

The following conclusion have been drawn from the present study:

- AISI 304 austenatic stainless steel (ASS) was successfully welded at different heat input by GMA welding without any observing any spatter proble.
- Heat input influence the mechanical and microstructural properties of weldments. At medium heat input weld was found best of quality.
- On increasing the heat input there is decrement in the UTS. It is due to the faster cooling rate
- Microstructure structure of AISI 304 weldment consisting of austenite matrix with little amount of δ-ferrite.
- Microhardness of weld bead decrease with increasing in the heat input.
- It was also observed that at medium heat input there is improvement in tensile strength, elongation, and hardness due to finer grain structure and smaller inter-dendritic spacing.
- In SEM fractrograph of welded joint ductile and brittle fracture mode was observed in toughness test samples with large dimples.
- Hardness of weld zone (WZ) is higher than the parent metal (PM) zone due to faster cooling and rapid heating.

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Persian Abstract

چکیده

در این کار تحقیقاتی ، AISI 304 از طریق فرآیند جوشکاری گاز بی اثر فلزی ((MIGبا آرگون (Ar) به عنوان گاز محافظ جوش داده شد. در مطالعه حاضر، AISI 304 با استفاده از الکترود استاندارد L۳۰۸ در معرض ورودی به گرمای مختلف قرار گرفت. کیفیت جوش یعنی مقاومت کششی نهایی، چقرمگی، ریز مقاومت و ریزساختار AISI 304 مورد بررسی قرار گرفت. ریزساختارهای اتصالات جوش داده شده با استفاده از میکروسکوپ الکترونی روبشی ((SEMمورد بررسی قرار گرفت ، به SEM متصل شد برای تعیین ترکیب شیمیایی فازهای تشکیل شده در رابط مشترک و از نتایج ، مشخص شد که در ورودی کم حرارت مقاومت کششی نهایی بالاتر است. نسبت به آنهایی که در گرمای متوسط و کم قرار دارند. از نتایج ، همچنین مشاهده شد که میزان درشت دانه در HAZ با افزایش ورودی گرما افزایش می یابد. همچنین مشخص شد که شکستگی نمونه های چقرمگی از نظر طبیعی شکننده بوده و نشانگر انعطاف پذیری کم و شکستگی شکننده است. ریزساختار منطقه جوش، -δفریت اسکلتی را در ماتریس آستنیت با محتویات مختلف فریت به نمایش گذاشته است. میکرو سختی مهره جوش با افزایش در ورودی حرارت کاهش می یابد. همچنین مشاهده شد که در ورودی گرمای متوسط، استحکام کششی، کشیدگی و سختی به دلیل ساختار دانه ریزتر و فاصله بین دندریتیک کوچکتر بهبود یافته است.