Analysis Of Shielded Metal Arc Welding (SMAW) On High Manganese Steel Hammer-mill Crusher

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ABSTRACT

Hammer-mill crusher is the main component of crushing machine, used to crush the material into smaller size. In this study the crusher was produced by casting in an induction furnace, which composition consisted of 1.64% C, 8.77% Mn, 2.56% Cr, and 3.75% Cu. Unfortunately, the production process frequently yielded undesirable defects such as blowhole, gas porosity and smooth - walled cavities, and the welding process was required to repair such defects. This study aimed to determine the welding parameters for hammer-mill crusher welding with Shielded Metal Arc welding (SMAW) process that covered the effect of welding current of 90A, 120A, 150A, welding speed of 0.8 mm/s, 1 mm/s, 1.7 mm/s and filler metal of AWS A5.5 (E7016) and AWS A5.13 (E7-UM-300K). The qualification standard for welding refered to The American Society of Mechanical Engineers (ASME) Section IX Welding and Brazing Qualification. The testing refered to ASME IX QW - 140 (purpose of the testing and inspection of welds) for tention test (QW-141.1) and visual examination (QW-144), ASME IX QW – 190 (other tests and examination) for Radiographic examination (QW – 191). The hardness test was performed to determine whether the hardness of weld pool is the same or close to the value of the hammer-mill crusher hardness. This parameter was important considering the function of hammer-mill as hard material crusher. The results showed that the optimum welding condition are: welding speed of 1 mm/ s, welding current 120A and filler metal AWS A5.13 (E7-UM-300K). The best results of mechanical properties include hardness 254 HV, elasticity modulus 277.261 MPa, and tensile strength283.605 Mpa.

Keywords: *Hammer-mill, Welding, Non Destructive Test, Destructive Test, Mechanical Properties*

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Introduction

The welding technique is widely applied in the fields of shipbuilding, bridge constructions, steel structures, pressure vessels, pipelines, vehicles etc. Moreover, the technique can be used to repair defects found in the hammer-mill crusher (HMC) foundry i.e. shape related defect, filling related defect and appearance related defect. HMC made of special material requires unique treatments including appropriate welding parameters, which in this case covers power, strength, hardness and corrosion resistance. Mechanical characteristics are important, which reflect the material ability to endure certain load without causing any failure and damage in HMC. The heat used in welding process will change the materials crystal structure and lead to the decline in physical and mechanical properties of welded material. Therefore, this study is conducted to identify and analyze optimum welding parameters used in hammer-mill crusher reparation with 8.77Mn + 1.64C + 2.56Cr + 3.75Cu composition. Shielded Metal Arc Welding (SMAW) uses a range of welding parameters such as filler metal, welding current and welding speed. Welds testing includes radiograph test that refers to ASME Sect IX QW-191, tensile test that refers to ASME Sect IX QW-150 and hardness test.

Litarature

Welding

Welding is a technique used to join two or more components based on principle of diffusion process. The advantage of welding technique include applicable for lightweight construction, ability to withstand high load, easy to operate and economic. In general, welding process could be classified into two categories: fusion welding (FW) and solid-state welding. In solid-state welding, the components are joined together using pressure without heating. In fusion welding, heat is required to melt the metal components or filler metal. The most common FW uses electric arc i.e. *Shielded Metal arc welding/ SMAW*. SMAW is an arc welding process in which coalescence of metals is produced by heat from an electric arc. The arc is maintained between the tip of a covered electrode and the surface of the base metal in the joint being welded [1]. *SMAW* uses simple and minimal equipment, make it easy to set and move to the desired location, more economical and ussualy used for welding steel, stainles steel, cast iron or high alloy metal welding [2].

In order to obtain welding with guaranteed quality, the process has to be complied with standard welding operation as described in Welding Procedure Specification (WPS) containing essential variables, supplementary and non essential variable [3]. The variables include welding speed, *welding current* dan *filler metal*. Some experimental work has been carried out to investigate the relationships between the heat source definition and the weld pool shapes. Painter, Numerical models of gas metal arc welds using experimentally determined weld pool shapes as the representation of the welding heat source [4] .

It had been shown that welding process parameters i.e. welding current and speed, greatly influenced the length of weld pool. The results also demonstrated that the welding speed, energy input and heat source distributions greatly affected the shape and boundaries of FZ and HAZ [5].

Based on study by Aslanlar S et al. (2005) welding current affected the quality of the weld joint. The study also clarify the effect of welding current on tensile shear and tensile peel strength of galvanized chromate steel sheets welding [6]. The amount of welding current required depends on the material and size of welds, the geometry of the connection and welding positioned. In the alloy steel welding, a small welding current should be used to avoid burning of alloy elements [7].

Welding speed on manual welding process highly depends on the welder’s skill and experience in controlling his/her arm movement in real time. In particular, the main challenge in process is maintaining the torch to travel at the desired speed [8]. To produce stable speed according to WPS requirement the welder needs to be trained. The speed (mm/s) is calculated by dividing the length of welds with average time required to finish the welding. Welding speed depends on the type of filler metal, the material to be welded, the geometry of the connection and the connection accuracy. Durgutlu et al. (1999) conducted a research on the influence of the microstructure of welding speed and penetration of the SMAW process [9]. The result revealed that the penetration decreased when the welding speed was lower or higher than the optimum speed. When welding speed was high, undercuts failure occurred at the edge of the welding beads and microstructure produced was fine grains structure, while the welding speed was low, weld metal would be piled up at the edge of welding bead, and the microstructure produced was large grain structure. Furthermore, the welding speed affected the hardness value on the HAZ and FZ [10] [11].

Inappropriate welding speed caused welding defect. Another study on welding parameters was also done by Ravikumar. S. M and Vijian P (2014), who conducted a research on the relationship of welding speed, gap welding, welding current to leak diameter in pipe welding with diameter 3 and 4 mm. The study concluded that the effects of welding current and welding speed were 54.64% and 22.96% on the welding results [12]. The relationship between the welding speed with the welding current is defined in Equation 1. The amount of heat input per unit length of welding to the type of electric arc welding is directly proportional to the current (I) and inversely proportional to the welding speed (Ws).

$$H = \frac{EI}{V}\left(\frac{J}{mm}\right) \quad (1)$$

Where E is the voltage (V); I is the current (A); and V is the welding speed (mm/s). Due to small electrical losses in the arc, the total heat does not reach the workpiece. The actual heat transferred to the workpiece in units of J/mm is defined as the net heat input (Hn) according to equation (2).

$$H_n = f_1 \frac{EI}{V} \quad (2)$$

Where f_1 is the heat transfers efficiency, which generally varied betwen 0.7 and 1.0 for arc welding. In this study f_1 value is set at 0.9.

The specific welding conditions used and the mean heat inputs obtained are shown in Table 1. Type of filler metal used will determine the welding results. Filler metal arcs welding functions as protection from the atmosphere, such as oxygen, nitrogen, and air, also to keep the bow steady and to control the fluid penetration at the weld joint. Barreda et al. (2001) had conducted an overview on various studies on the addition of filler metal in fusion area to solve the problems in terms of porosity, notching, or cracking susceptibility on the connection[14]. Filler metal can also be used in welding plates with high thickness and low power electron beam welding as practiced by Ruge and Oestmann *etal.* in Barreda *etal.* 2001 [15].

Hammer-mill crusher

Hammer-mill crusher is the main component of stone crushing machine. Its functions is to hammer materials (eg. stone, dolomite, etc.) and to crush materials into smaller sizes. Hammer-mill crusher is located on the main axis of hammer-mill crusher machine [16]. Currently, the material used to manufacture hammer-mill crusher is manganese steels which are durable and hard in spite of low carbon content. This research focuses on manufacturing hammer-mill crusher with the addition of 3.75% Cu. The addition of Cu was intended to improve the corrosion resistance and increase the yield stress (yield strength) on the steel material [17]. During the manufacturing, undesirable defects still occurred due to surface defect in the molding phase. The defect affected the durability and lifespan of casting products. Casting defects can be classified into four groups: 1) filling related defects; 2) shape related defect; 3) thermal defects; and 4) appearance related defect [18]. An example of hammer-millcrusher casting defects can be seen in Figure 1.

Figure 1: HMHs Casting Defects

Method

The input parameters used are filler metal, welding current and travel speed. The welding currents employed are 100A, 130A, and 150A, while the filler metals used are two types of AWS A5.5 (E7016) and DIN8555 (E7-UM-300K) with three variations of welding speed: 0.8 mm/s, 1 mm/s, 1.7 mm/s (Table 1).The filler metal specifications can be seen in Table 2. Coupon test which is formed into single V-groove weld can be seen in Fig. 2.

Table 1: Welding parameters

No	Filler Metal	Dia. (mm)	Volt. (V)	Curr. (A)	Tr. Speed (Avg.) (mm/s)	Heat Input (kJ)
1	AWS A5.5 (E7016)	3,2	23	90	0,8	2,59
2	AWS A5.13 (E7-UM-300K)	3,2	23	90	0,8	2,59
3	AWS A5.5 (E7016)	3,2	23	120	1	2,76
4	AWS A5.13 (E7-UM-300K)	3,2	23	120	1	2,76
5	AWS A5.5 (E7016)	3,2	23	150	1,7	2,07
6	AWS A5.13 (E7-UM-300K)	3,2	23	150	1,7	2,07

Welding process: SMAW

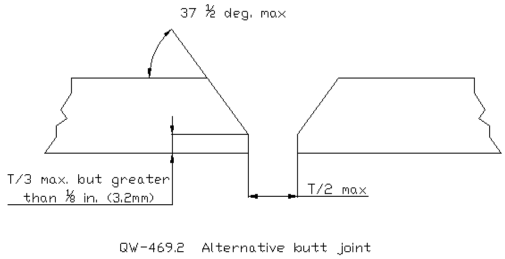

Figure 2: Butt joint design

Hammer-mill Crusher is manufactured using high manganese steel produced using induction furnace "Inductotherm" 700 kg capacity, by Laboratorium Of Research Unit for Mineral Processing – LIPI located in Jl. Ir. Sutami Km 15 Tanjung Bintang, South of Lampung - Indonesia. The steel consists of 1.64% C, 8.77 % Mn, 2.56 % Cr and 3.75 % Cu and other components as presented in Table 3. After casting the steel sample was shaped by machine to form single V groove with 37.5 angle (Figure 2).

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Table 2: Spesification of filler metal

Types of filler metal	Yields (Kpsi)	Weld. position	Weld. polarity
AWS A5.5 (E 7016)	70 = 70.000 psi	1 = All Position	6
AWS A5.13 (E7 – UM – 300 K)	7 = Mn austenite with 11 - 18% Mn and more than 0.5% C	UM = Coated	300 = >325 – 375 HB

Table 3: Chemical composition

	C	Si	Mn	Cr	Cu	Mo	Ni	V
Hm-C	1.64	0.10	8.77	2.58	3.75		1.0	2.0
AWS A5.5 (E 7016)	0.08	0.3	1.4		0.6		0.8	
AWS A5.13 (E7-UM-300 K)	1.00	0.59	1.5	8		1.3		

Welding Procedure Specification (WPSs) had been composed with predefined parameters as reference for the welder to finish the welding. Hammer-mill crusher tests pieces are made as many as 6 pieces. After welding is done, the sample is analyzed with non-destructive test (NDT) and destructive test (DT). NDT includes visual inspection (VI) and radiograph testing (RT). VI is aimed to determine visible defect and dimension changes after welding, which results used to determine the acceptance/rejection of welding results. This test has to be authorized by the welding inspector [10]. VI is performed by spraying liquid penetrant to the welding area. RT refers to ASME Sect. IX QW – 191.

ASME Sect. IX QW – 191 explains that linear indications i.e. cracks, incomplete fusion, inadequate penetration, and slag are represented on the radiograph as linear indications in which the length is more than three times the width. The standard acceptance criteria shall be judged based on unacceptable excess of the limits specified on any type of crack or zone of incomplete fusion or penetration [3]. RT is performed in First Nutrindo (Co) Laboratory under a supervision of NDT level II. Weld defects based on NDT among others are welding Crack, Incomplete Fusion, and porosity. According to Gabriel Rihar (2000), an incomplete fusion welding defects occur due to the joining of welding material with the base metal or between the previous weld bead. Meanwhile, the causes of porosity include wet or damp environment, moist electrode, too high capping amperage, arising gas during welding, non-grounded galvanized coating, air penetration into the weld pool, and dirty weld fusion. Criteria for acceptance of individual porosity is less 1/8 or 25% of nominal thickness, for flocking porosity is less than half of diameter and does not exceed the length and 12 welding cluster [19].

Figure 3: Tensile strength test

Destructive test included Tention Test (refers to ASME Sect. IX QW – 150) and Hardness Test (HT). Tensile strength values were calculated by dividing the maximum load at the time of the test piece was broken into smaller cross-sectional area. The results of tensile strength test of the welded joints including weld fusion zone should be greater than or equal to the minimum tensile strength of the base metal. Tensile test specimen was established in accordance to ASTM E8 for rectangle specimen on rod tensile test for metallic materials. Tensile test was conducted at the Laboratory of Mechanical Engineering, University of Lampung. HT was conducted on the base metal, Heat Affected Zone (HAZ) and Fusion zone (FZ), which was performed in Laboratorium Of Research Unit for Mineral Processing – LIPI.

Results And Discussion

Visual examination on tested pieces obtained showed that sample 5 does not meet admission standard of welding (Fig. 4). From Fig. 4, it is clearly visible that crack occurred in the weld region along the width of the workpiece. The sample uses current welding parameter of 150A, filler metal AWS A.55 (E7016) with a welding speed of 1.7 mm / s.

Figure 4: Cracking at sample 5th

VI examination is clarified by RT result. Fig. 5 shows that crack occurs in all areas along the HAZ. The Crack is often called longitudinal crack whether under bead crack or shrinkage crack, which occurred mainly due to the heat received by the weld material with fast cooling rate, leading to excessive tension shock. The hammer-mill which is too small causes the area to be exposed to heat and making cooling rate becomes too fast. Fast cooling rate was also caused by small area of HMC.

Based on observation, crack occurs at the connection between the filler metal with the base metal and this piece was recommended to be rejected. Crack (in sample 5) happened when it used filler metal AWS A5.5 (E7160) with the current at 150 A, higher than the others. Higher current caused filler metal melted fast but the cooling rate was also fast due to small area. This condition produces incomplete fusion of filler metal and base metal connection making the joint of samples incomplete.

The chemical composition of this filler metal consists only 1.4% Mn and 0.6% Cu while the Chromium is 0%. This chemical composition is much different with Hammer-mill crusher chemical composition of 8.77% Mn, 2.58% Cr, and 3.75% Cu. Compared with Filler metal AWS A5.13 (E7-UM-300K), the chemical compositions are higher, i.e. 1.5% Mn and 8% Cr. The difference of chemical composition between filler metal and base metal causes the non-occurrence of fusion between the base and the filler metal.

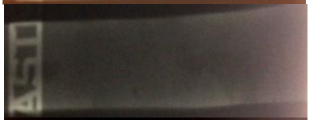
No. Sample	Filler Metal	Tr. Speed (Average) (mm/s)	Welding Current (A)	Radiograph Result	Remarks
1	AWS A5.5 (E 7016)	4,8	90		
2	AWS A5.13 (E7-UM-300 K)	4,8	90		
3	AWS A5.5 (E 7016)	6	120		
4	AWS A5.13 (E7-UM-300 K)	6	120		
5	AWS A5.5 (E 7016)	10	150		Crack
6	AWS A5.13 (E7-UM-300 K)	10	150		

Figure 5: Radiograph Test Result

The hardness test result (fig.6) indicates the decrease value of hardness in weld pool area compared to base metal hardness. The lowest hardness occurred in sample 6 with filler metal AWS A5.13, 1.7 mm/s in speed travel, and 150A current. However, sample 3 with filler metal AWS A5.5, 1 mm/s speed travel, and 120A current also produces decreasing hardness value. Selection of filler metal using AWS A5.5 (E 7016) and AWS A5.13 E7-UM-300K does not affect metal hardness in the sample tested. There was slight hardness increase in the case of filler metal AWS A5.13 E7-UM-300K compared to AWS A5.5 (E 7016). This was probably caused by the melt of filler metal produced by heating during and cooling after welding process. The highest hardness occurred in sample 4 with average value of 254 Hv, obtained from welding speed and welding current parameters of 1 mm/s and 120 Ampere, respectively.

Tensile strength test on sample pieces was carried out after the pieces was inspected. The highest tensile strength result is obtained at 283.605 MPa using welding filler metal, welding speed and welding current ofAWS A5.13(E7-UM-300 K), 1 mm / s, 120 Ampere respectively. The highest tensile strength occurs in sample 4 as shown in Table 4.

Table 4: Tensile Test Result

Sample No.	Strength test	Value	Units
4	Tensile Strength	283.605	MPa
	Yield strength	12.830	MPa
	Fracture strength	283.605	MPa
	Elasticity modulus	277.261	MPa

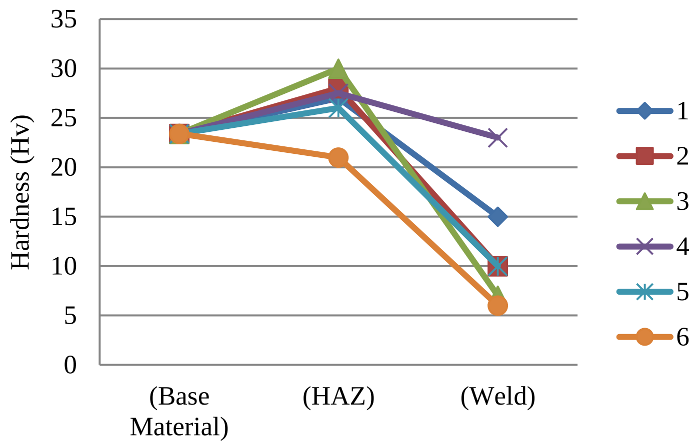


Figure 6: Hardness test results

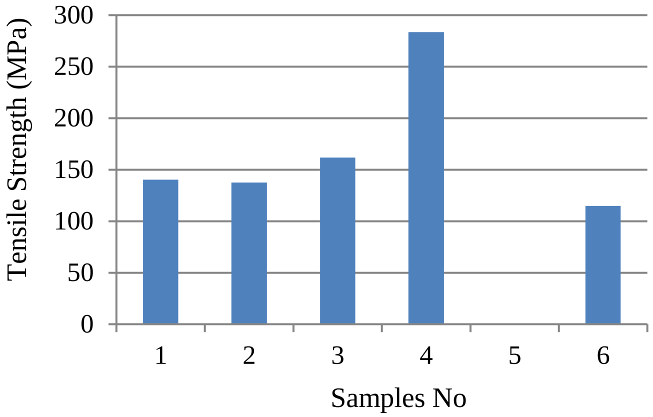


Figure 7: Tensile Strength test results

Filler metal AWS A5.5 (E 7016)has an average value of tensile strength which is lower than AWS A5.13 (E7-UM-300K). The welding speed chart showed the highest value of tensile strength welding speed of 1 mm /s when compared to other speed. Similarly, the welding current 120A has the highest value of tensile strength when compared to other currents. Microstructure etching was performed using pycral 2% mixed with 80% alcohol. Figure 8 presents base metal (Hammer-mill crusher, Manganese steel with 80.77% Mn) before any treatment. The arrows in Fig. 8 shows the changes in the form of carbides "thin" to "thick". Wide grain boundary changes to move closer. In practice, the presence of grain boundary carbides is typical, especially in areas that are heavier. Usually the first manganese steels carbide thin delineation and quickly envelop the grain boundaries [20]. The hardness in this area is about 254 HV and 283.61 Mpa of the tensile strength.

Figure 9 shows weld defects such as crack in the sample (arrows). The crack occurs between the base metal welding areas and this phenomenon confirms the supposition of non-fusion chemical composition of filler with base metal. Base metal (fig. 8) shows austenite with widened structure while HAZ region (fig. 9) shows apparent formation of martensite structure, marked by irregular scattered lines of needles. In this HAZ grain, boundary region shrinks and becomes invisible.

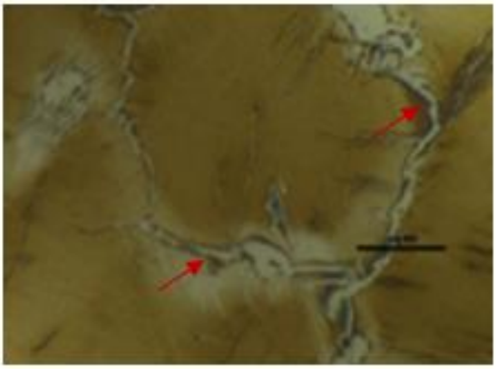


Figure 8: Base metal microstructure

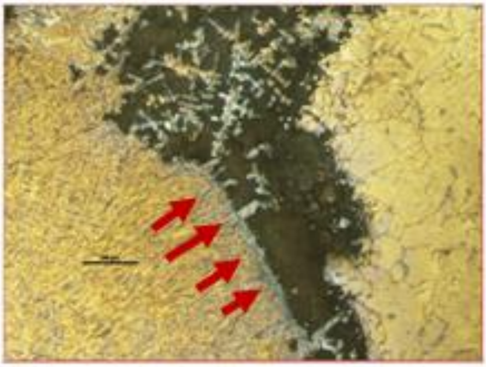


Figure 9: Crack of sampel 5th microstructure

Austenite transformed into martensite in the forms of scattered needles during heat treatment of Base Metal (Hammer-mill crusher) in the welding process and rapid cooling after that as indicated by small dimension of HMC. The hardness at HAZ tended to increase to 263 Hv.This was due to the characteristic of martensite structure with high hardness value. However, the hardness at weld zone tended to decrease to 247 Hv, which was affected by the hardness of the metal filler used.

Conclusion

The Shielded Metal Arc Welding (SMAW) process could be used to repair Hammermill crusher defects. The Hammermill crusher had to be produced using materials with high hardness and high tensile value for crushing and grinding purposes, so that it required optimum welding parameters including filler metal of AWS A5.13 (E7-UM-300K), current of 120 A, and speed average of 1mm/s.

Welding process optimally repairs Hammer mill crusher with high hardness results without weld defects. Filler choice with the same chemical composition with Hammer mill crusher was needed to get full fusion between the filler metal and base metal, while hardness was needed considering the function of Hammer mill crusher as hard material crusher. Preheat is suggested before welding and post weld heat treatment (PWHT) after welding to prevent heat shock at base metal.

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