

Mechanical Properties and Microstructures of Friction Welded Mild Steel

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Abstract

Friction welding, one of solid-state welding methods, is very popular way to join cylindrical component since it offers many advantages over fusion welding problems in porosity and inside tightens of cooling leads to decreasing of joint strength. In order to produce sound welding by friction welding methods, a careful choice of welding parameter need to be carefully selected. The choice is in acordance with material of workpiece.

Welding time is one of important process parameter since it governs the heat generated during weld and also affects coefficient of friction. Welding time variation of 30, 35, 40, 45, and 50 seconds was selected to investigate the influence of welding time to mechanical properties dan microstructure of friction welded S45C. Hardness test in Brinell and optical microscope was employed to present the hardness and microstructural changes in base metal, HAZ, and weld metal are.

This research shown that in term of hardness, the weld metal has highest hardness followed by HAZ and base metal. The hardest area was produced by employing 35 and 45 seconds of welding time in weld metal area while the lowest was 50 seconds welding time in base metal area. For microstructure, weld metal area was superior than others area with HAZ strength decreases contained of pearlite of 69.17% and ferrite up to 30.83% while in the area of base metal, the strength decreased significantly with the contained percent of pearlite up to 68% and ferrite by up to 32%.

Keywords: Mechanical Properties, Microstructures, Friction Welding, Welding Time, Mild Steel.

1. Introduction

Friction welding process is a pressurized welding method in contrast to melt (fusion) welding. The process has a long history as the first trial goes back to 15th century. The welding process found widely application after 1960's when a Russian and Caterpillar Tractor Co. patented conventional friction welding and inertial friction welding respectively and become most widely welding methods after electron beam welding. It is a solid state process where no other power sources are used other than mechanical energy generated by friction between interfaces of the parts. Succesful welding process is much dependent on how efficient it distribute heat on the surface in which welding will be applied. At first, heating phase take place where surface are under pressure and temperature increase until it achieve plastic forming temperature. After the temperature achieved, heated metal then accumulated because of increasing pressure lead to thermomechanical treatment and makes the regions transforms into stable particle structure [Uzkut et.al. [1]]. The application of friction welding found mainly for welding of pipe and circular rod.

Eventhough the process already has success, but the full knowledge of process is not completely clear, so that experimental study and practical application need to be conducted in parallel to address this problem especially in finding optimum parameters in welding of certain material. In most cases, the weldability of material is governed by the strenght of material and its deformation capacity under heat. The strength need to be high enough to withstand pressure induced by axial pressure and torque. Also the material must exhibit enough heat treatment deformation behaviour for joining process quality [Uzkut et.al. [1]].

There are three physical phenomena in welding which govern welding parameters, i.e. temperature, stress, and strain [Fu et.al. [2]]. It was known that thermomechanical behaviour at the interface is critical to the quality of weld. The heat generated in friction welding is depending on coefficient of friction, friction pressure, part rotating speed, and diameter of workpiece. Coefficient of friction is a function of friction pressure and rubbing speed, and varies with diameter of workpiece and time. All this relationship is a complicated one.

The predetermined value of heat generated by friction and pressure into surface of joined metals give results in binding of the surface of atoms when they close together during plastic deformation as product of upsetting of welded element contact boundary [Ptak [3]]. Metallic bonds occured by interraction between the neighbouring atomic planes of the crystal lattice of metals being welded sufficiently close enough to each other and undergone plastic strain in HAZ of a friction welded joint.

In this report, time variation on welding was chosen as variable to investigate its influence on microstructure and hardness of weld joint. It is interesting to be explored because the reports on this area are still not widely available. The report mainly focused on the microstructural examination on base metal, weld metal and HAZ and also its hardness of friction welded S45C shaft. The effect of time variation on hardness and correlation of microstructure and hardness also was discused.

2. Literature Review

2.1 Friction Welding

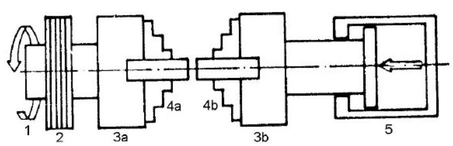
Friction welding is categoryzed as solid-state joining which produce coalescence in material using heat generated from friction and load between surfaces. The friction is the result of rubbing motion and together with applied load produce forged quality joint. During the process, the surfaces do not melt and the process doesn't need filler metal, flux and shielding gas. During the process, surfaces are under pressure, and called heating phases, until plastic forming temperature is achieved. During this phase, heated metal at the interface are accumulated by increasing pressure. When rotational speed is increasing, axial pressure is applied and local heating occurs at the interfaces. After this stage, rotational movement is stopped and heated material accumulated at the interface.

In general, friction welding is divided by two type of process, 1) continuously induced friction welding, and 2) flywheel induced friction welding as illustrated in Figure 1 below.

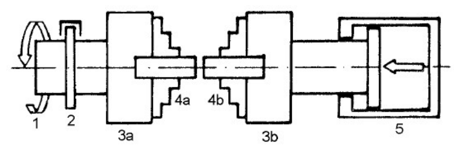
The other type of friction welding is combined friction welding which is combination of two process mentioned before. Generally, the proces has capability to weld vast type of material, simmilar and dissimilar one.

2.2. Process Parameters

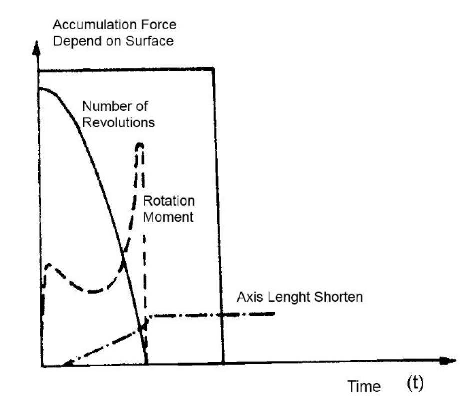
In friction welding, important process parameters are diameter of workpiece, part rpm, friction contact time, forging delay time, forging time, time of increased friction pressure, and friction pressure [Uzkut et.al. [1]]. Also forging pressure and rotational speed can be considered as others process parameters [Maman Suratman [2]]. The rotational speed control magnitude of moment, uniformity of heating, and formation of intermetallic compounds. Lower rotational speed causes enormous moments and non uniform heating while higher rotational speed makes HAZ widens without affecting power supply. Friction pressure and friction time then need to be controlled in order to prevent overheating. The temperature gradient is believed to be controlled by pressure value which in turn also affects torque and also power [Uzkut et.al. [1]].



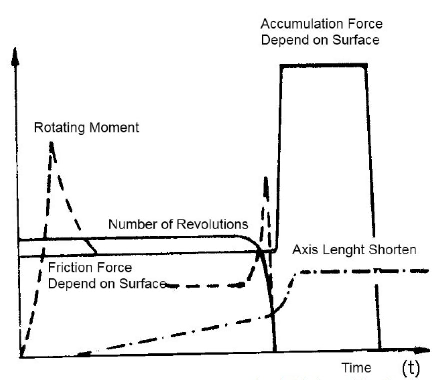
a). Schematic of Fly Wheel Induced Friction Welding Machine



b). Schematic of Continuous Inducement Friction Welding Machine



c). Parameters of Fly Wheel Induced Friction Welding Machine



d). Parameters of Continuous Inducement Friction Welding Machine

Figure 1 Two Type of Frition Welding [4] [5]

Geometry and material properties of part has direct relationship with friction and forging pressure. Applied forging force will governs the power needs. Bigger force will need bigger power and vice versa. Increasing of force will also increase energy input that in turn narrowing HAZ, accelerate metal displacement ratio and reduce welding time. As a result, heat band on boundary is formed. The forging pressure variable can be controlled by temperature in welding region and decrease in axial length. To have uniform deformation troughout, the optimum pressure must be applied [Uzkut et.al. [1]].

In order to remove oxide during welding, high enough friction pressure need to be applied which also makes uniform heating and interrupt affinity between surface and air. The forging pressure should be chosesn for optimum value since too high pressure will lead to welding accumulation and too low pressure will cause under welding. The value of forging pressure is much dependent on material properties especially the lower one in case of dissimilar weld. Value of friction and forging time usually directly depend on material properties. The friction time must allow plastic deformation to occur or remove possible residuals and particles therefore minimum fiction time need to be exceeded first in order to produce good welding. Lower friction time together with non uniform heating will produce non-joined areas at the inteface and also inadequate plastic deformation, a sign of low quality weld. In contrast, higher friction time will produce rough structure and wide HAZ. This become important especially in welding dissimilar material because formation of undesired substance also overheating and material loss may occurs [Uzkut et.al. [1]].

3. Methods of Research

The material for the research was JIS S45C. The chemical composition of material is presented in Table 1. JIS S45C is a medium strength steel suitable for shaft studs, keys etc. It is available in the market as rolled or normalized square bar, round bar or flat. It has good machinability and weldability properties and heat treatable.

Table 1. Composition of JIS S45C Mild Steel [6]

Chemical Composition (%)								
C	Si	Mn	P	S	Cu	Ni	Cr	Ni+Cr
0.42-0.48	0.15-0.35	0.60-0.90	⩽0.030	⩽ 0.035	⩽0.30	⩽0.20	⩽0.20	⩽0.35

Investigation of mechanical properties and microstructure of weld employed conventional lathe equipped with special apparatus for friction welding purposes. The rotational speed of part was 1800 rpm and forging pressure could be varied by adjusting load. Friction contac time was varied for 30 seconds, 35 seconds, 40 seconds, 45 seconds, and 50 seconds.

Figure 2. Friction Welding Process

After welding was completed, then speciment was taken to hardness tester for base metal, weld metal and HAZ area hardness. The indentation points were chosen to follow pattern as depicted in Figure 3 below.

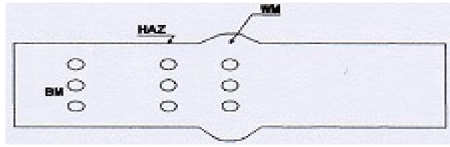


Figure 3. Indentation Points for Hardness Test

Also, micropotograph of base metal, weld, and HAZ area to get the microstucture of metal was conducted using optical microscope with 400x magnitude after etching.

4. Results of Research and Discussion

4.1 Welding Product

Figure 4 below shows the welded shaft by friction welding methods. Visually, the flash formed during welding has different shaped for each time variation. In genereal it follows the rule that the longer of welding time, the bigger flash will developed.

(a) 30 sec welding time

(b) 35 sec welding time

(c) 40 sec welding time

(d) 45 sec welding time

(e) 50 sec welding time

Figure 4 Welded shaft by friction method

4.2 Hardnes Test

In this study, each region conducted a three point hardness test, as for the value hardness test are as follows:

Table of Hardness Testing Value

No	Rotation (Rpm)	Variation Duration(Second)		Average Value of Hardness (HRB)		
				Weld metal	HAZ	Base Metal
1	1800	30 s	1	72	68	67.5
			2	74.5	68	64.5
			3	73	66	65
			Average	73.16	67.33	65.66
2	1800	35 s	1	74.5	73	70
			2	74	69	68
			3	73	69.5	71.5
			Average	73.83	70.5	69.83
3	1800	40 s	1	72	69	66
			2	71.5	70.5	66.5
			3	71	69	66.5
			Average	71.5	69.5	66.33
4	1800	45 s	1	74.5	66.5	66
			2	73.5	67.5	68.5
			3	73.5	69.5	67
			Average	73.83	67.83	67.16
5	1800	50 s	1	68	67.5	66
			2	69.5	67.5	66
			3	67.5	66.5	65
			Average	68.3	67.16	65.66

Based on the result table of hardness testing value, the average values of hardness (HRB) are illustrated in the chart as below:

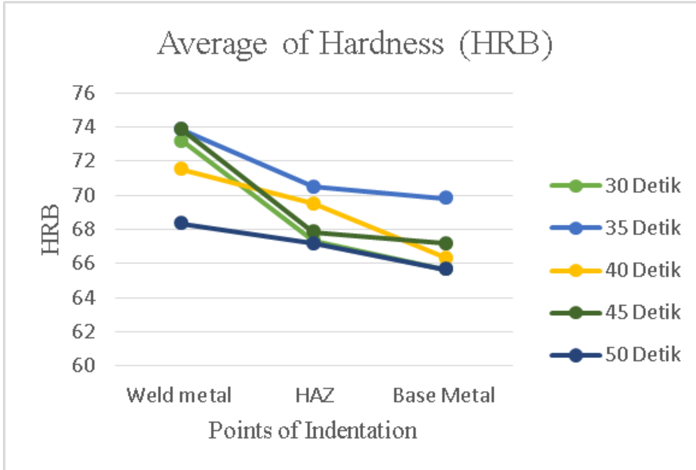


Figure 5 Average Hardness Value for Welded Joints

Based on the chart, the hardness of welding product with variationa of welding time shown that the hightest value of hardness of *Weld Metal* area were of welding time 35 seconds and the welding time 45 seconds with an average value of 73.83 HRB. Others welding time, of 30 seconds, 40 seconds, and 50 seconds shown the average value were lower. The lowest value of *Weld Metal* hardness was for welding time of 50 seconds with the average value 68.3 HRB.

For HAZ area, it was shown that highest value of hardness was achieved in welding time of 35 seconds with an average value of 70.5 HRB. While others welding time, 30 seconds, 40 seconds, 45 seconds, and 50 seconds haslower average hardness value of 67.16 HRB.

This result is in accordance with Nur Husodo et al [7], in the results of the hardness test of weld metal area which was higher than HAZ and categoryzed as good welding since it will not break on the weld metal (connection), but in the HAZ area.

In the hardness of base metal area shown in Figure 5 above, the highest value of hardness was of welding time of 35 seconds with average value 69.83 HRB. Other welding time, of 30 seconds, 40 seconds, 45 seconds, and 50 seconds, the average value was lower than welding time of 35 seconds. The lowest value of hardness of base metal area was welding time of 50 seconds with average value of 65.66 HRB.

These results also in accordance with Poedji Haryanto et al [8], which have been successfully conducting welding with good results as shown in increase of hardness in the welded area area reached 65 HRB while the hardness of base metals was about 52 HRB.

From the research that has been conducted with variation of welding time of 30 seconds, 35 seconds, 40 seconds, 45 seconds and 50 seconds with the rotation 1800 Rpm and a load of 3.5 Kg, the hardness test shown that the value of hardness decreased in the area base metal when compared with HAZ area and the weld metal area.

4.3 Mirostructure

Weld metal is an area that most experiences changes in the microstructure because of higher heat input than HAZ and base metal where weld deposition and solidification of metal occur during welding. From the hardness test, it can be shown that the area produce relatively harder area that HAZ and base metal. The microstructure of each area started from weld metal, HAZ and base metal were depicted in Figure 6, 7 and 8 below.

Microstructure of weld metal

In the Figure 6 below shown that the largest percent of perlite in the specimen was of 35 seconds of welding time, it was up to 69.75%. While in the speciment 50 seconds had significant decrease in the percent of perlite in the amount of 56.25%, but the percent of ferrite structure has increased up to 43.75%. This was in accordance with the hardness test which shows that the welding area of 35 seconds of time welding have the highest level of hardness than the others.

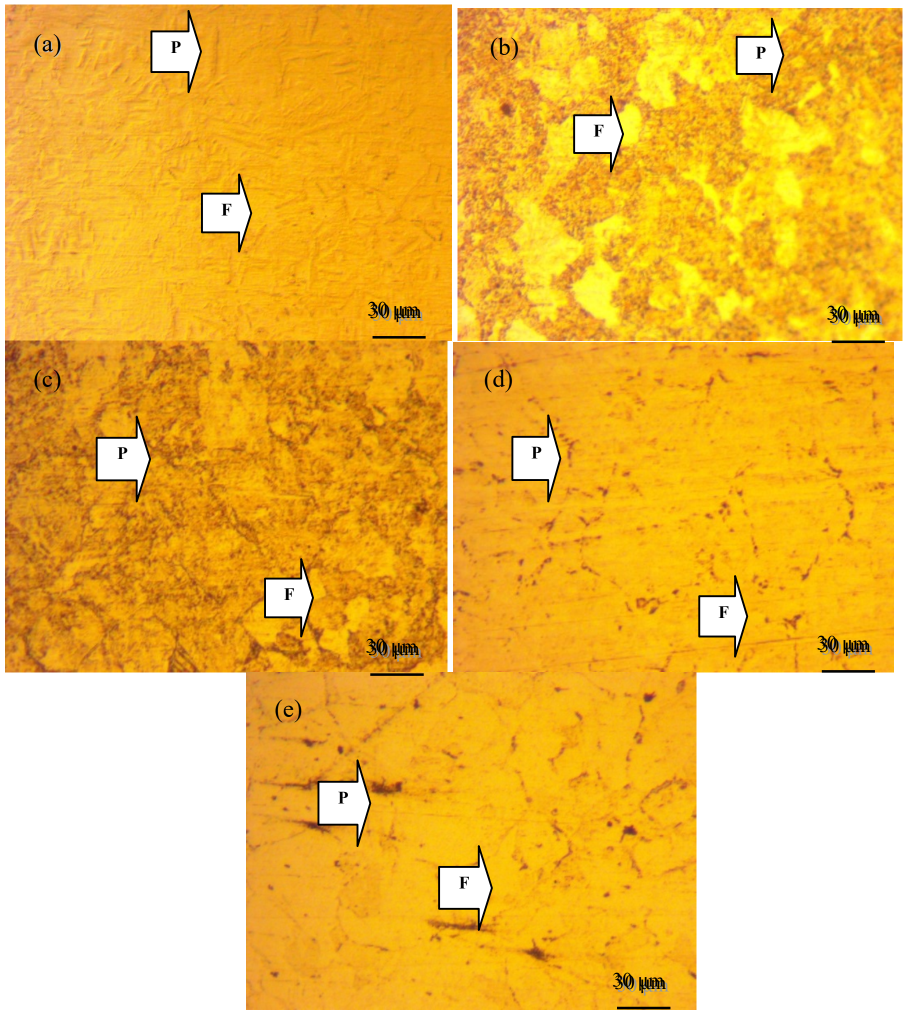


Figure 6. Microphotograph of Weld metal with 400X magnification. (a). Friction contact time of 30s, (b). Friction contact time of 35s, (c). Friction contact time of 40s, (d). Friction contact time of 45s, (e). Friction contact time of 50s

Microstructure of HAZ (Heat Affected Zone)

HAZ (Heat Affected Zone) is the base metal area that gets influence from the heat of welding and the microstructure was changed becausi of the effect of heat welding.

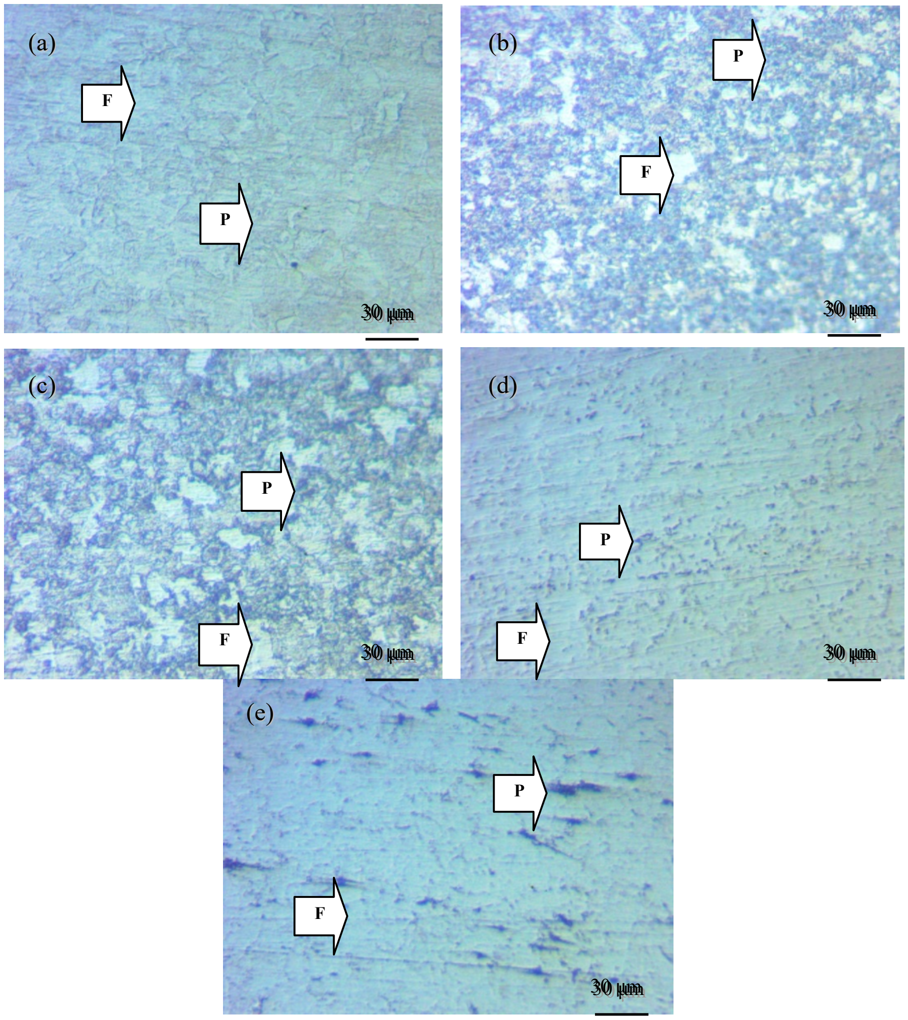


Figure 7. Microphotograph of HAZ (*Heat Affected Zone*) with 400X magnification. (a). Welding time of 30s; (b). Welding time of 35s; (c). Welding time of 40s; (d). Welding time of 45s; (e). Welding time of 50s

In the picture above shows that the largest percent of perlite contained in the specimen was of 35 seconds of welding time up to 69.17%. In the speciment of 50 seconds of welding time, it had significant decrease in the percent of perlite up to54.58%, but the percent of ferrite structure had increased up to 45.42%. This shows that the welding area with welding time of 35 seconds has the highest level of than the others.

Microstructure of base metal

Base Metal is a metal part that is not affected by the heating because the welding process and temperature during the welding process does not much change the structure and properties of the base metal.

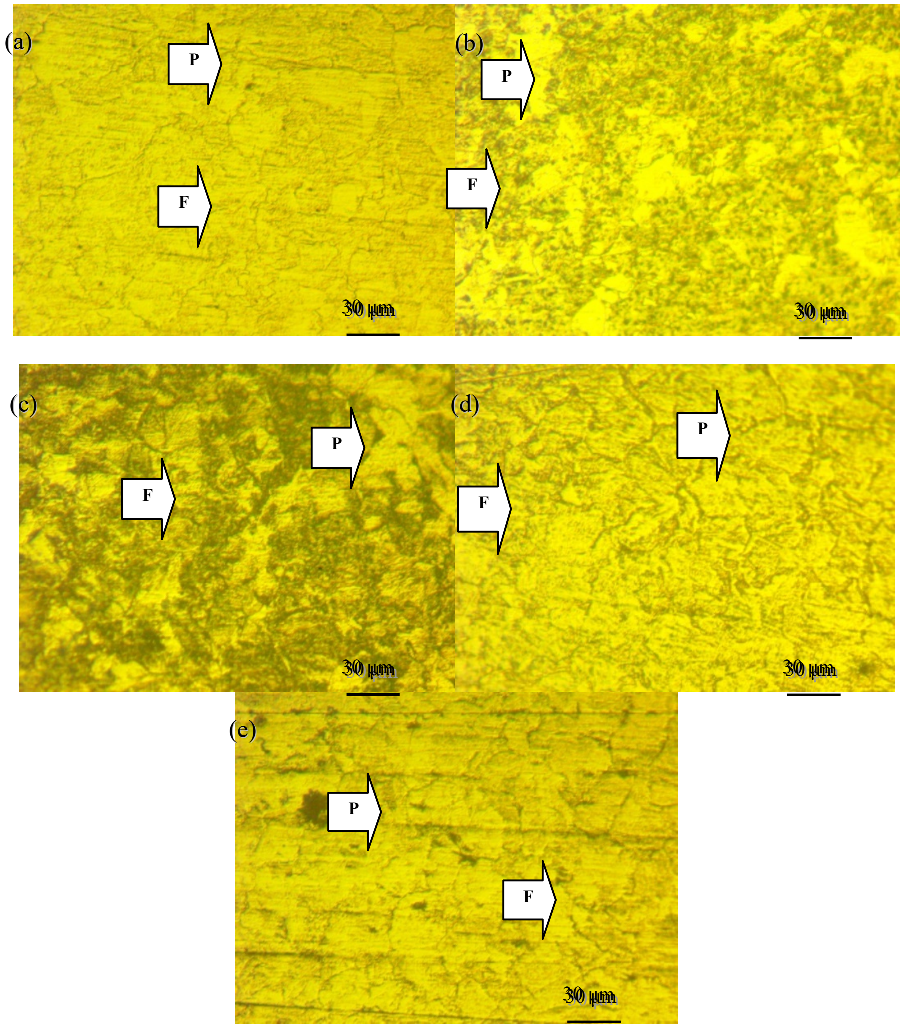


Figure 8. Microphotograph of HAZ (*Base Metal*) with 400X magnification. (a). Welding time of 30s; (b). Welding time of 35s; (c). Welding time of 40s; (d). Welding time of 45s; (e). Welding time of 50s

In the Figure 8 above shows that the largest percent of perlite contained in the speciment was of 35 seconds that is up to 68.00%. In the speciment of 50 seconds, it had significant decrease in the percent of perlite up to 52.75%, but the percent of ferrite structure has increased up to 47.25%. This shows that the welding area with welding time of 35 seconds have the highest level of hardness than the others.

From the results of microstructural test, the area of the weld has very tight microstructure, much of them was pearlite. The effect of heating will change the initial microstructure and together with normal cooling effect (air) made the size of the grain turns into a fine perlite caused the hardness in the welding area is higher, but more resilient. This microstructural changes also affect the mechanical properties. The mechanical properties can be changed if it was influenced by three things, such as heat treatment, changes in the composition of the materials, and a variety of manufacturing processes in material.

According to Husodo et al [7], it showed that the microstructure of weld joint contained more pearlite than ferrite and producing the better weld joint quality. Also according to Haryanto et al [8], the microstructure in the form of metal grain of basic materials was bigger, while metal grain in metal welding was smaller because of the effect of cooling and deformation on the surface of the weld joint, microstructure on weld joint also showed solidification structure compared to outside weld koint.

5. Conclusion

From the results of friction welding JIS S45C steel, it have been conducted using rotation of 1800 Rpm, a load of 3.5 kg and variations in the welding time of 30 seconds, 35 seconds, 40 seconds, 45 seconds, 50 seconds and after testing of the hardness and microstructure, it can be concluded that the speciment is the most ideal and has the highest hardness was speciment with wedling time of 35 seconds with hardness of 73.83 HRB in the weld metal area, 70.5 HRB in the HAZ area and 69.83 HRB in the base metal. If the friction time is too long then the value of hardness at the weld will decrease again. So it can be shown that the time duration friction affect the hardness and mechanical properties of friction welding results.

For speciment with welding time of 35 seconds, it produced the highest percent of pearlite in the weld metal that was up to 69.75% and ferrite up to 30.25%. It can be seen that the duration of friction affects the formed microstructure resulting of microstructure containing more pearlite than ferrit and produce hardness in the welding area higher, but more resilient.

Of all the speciment, the hardness and microstructure of weld metal area was superior than others area with HAZ strength decreases contained of pearlite of 69.17% and ferrite up to 30.83% while in the area of base metal, the strength decreased significantly with the contained percent of pearlite up to 68% and ferrite by up to 32%.

In conclusion, friction welding process can be used as alternative methods to connect the component in better ways, although there were technical operation difficulties.

6. References

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