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A Comparative Study: Life Extension of Weld Surfacing of AISI 4340 High Tensile Strength Low Alloy Steel

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Abstract: This research studies the fatigue behavior of welding surface of Low Alloy Steels with Shield Metal Arc Welding (SMAW), Metal Active Gas Arc Welding (MAG) and FluxCored Wire Arc Welding (FCAW) process. For reduction of residual stress, the test specimens were heated to a temperature of 350°C before welding and heated to 550°C for 1 h after welding. The test specimens were welded by Shield Metal Arc, Gas Metal Arc and FluxCored Arc welding process. The study on fatigue strength shows that the weld metal produced by FluxCored Arc welding process gives the best fatigue strength but slightly lower than that of the Low Alloy Steels AISI 4340. For failure analysis and assessment on lifespan of shafts that were made from high tensile steel AISI 4340 which are used in transmission of electric cable shovel, it gives the benefits of choices to select the most suitable welding process. By studying on cracking surface and mechanical problem solving process in deteriorations from fatigue under full loading capacity of the working electric cable shovel, it reveals that the stress concentration area initiated the rupture. The assessment on the useful life of transmission shafts in the form of cycle loading indicates that welding repair process with welding resurfacing by FluxCored Arc welding process gives the longest lifespan.

Key words: Welding surface, FluxCored Arc welding, shield metal arc welding, electric cable, cycle

INTRODUCTION

The amount spare parts of heavy machinery (Lin *et al*., 2008) such as Swing Shaft, Shipper shaft, Final drive shaft, Final Pinion Shaft shown in Fig. 1 especially for those in the EGAT (Electricity Generating Authority of Thailand) Mae Moh mine, cost >10 million baht each year. This group of spare parts was produced from low alloy steels which has high ultimate tensile strength of 1200-1300 MPa, high impact strength and good bearing capacity under dynamic loading. After using for a period of time and meeting the maintenance schedule, numerous amount of spare parts were found as severely eroded or having fatigue cracks which led to the termination of usage or to repair processes. These damages led to the purchasing of substitute spare parts which increased the cost of nation's electricity generation, causing the loss of foreign currency. In maintenance program for prolonging the lifespan of spare parts, welding repair process by welding resurfacing on build-up was performed (Sitthipong *et al*., 2001; Sham and Liu, 2014; Lin *et al*., 2008). The main reasons of using welding resurfacing on build-up which is one of the selected method used to repair the surface of spare parts that are severely eroded or having fatigue cracks were due to the quality of welding repair process which gives the closest properties to the original part and due to its cost-effectiveness when compared to the cost of the replacement.

In normal cases, Shielded metal arc welding process was used. With normal loading, it was found that the lifespan of spare parts that undergo welding process was satisfied at some level. But in case of over load, disoperation or work accidents, the welding repair process of spare parts shorten its lifespan since the repair process by welding was limited by the strength of the weld material and welding processes (Magudeeswaran *et al*.,

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Fig. 1 The swing shaft in transmission system

2008a, b; Lin *et al*., 2008). From the information and reasons that were stated, the objective of this research project is to identify the appropriate welding repair processes to prolong the lifespan of the spare part.

MATERIAL AND METHOD

Knowledge of weldingrrepair process (SMAW, MAG and FCAW): All three methods of welding process (SMAW, MAG and FCAW) and kinds of electrode that were used led to differences between the microstructure around the weld metal and around the Heat Affected Zone (HAZ), affecting the resistance properties to fatigue. At present day, prolonging the service life of spare parts and machinery parts such as shaft or gear, by resurfacing is an effective technique. In normal cases, the shielded metal arc welding process is used for resurfacing which it gives a satisfactory amount of lifespan of the welded work piece in normal load. But in abnormal cases such as overload, disoperation or work accidents, the welding repair process shorten the spare part's lifespan since the repair process by welding was limited by the strength of the weld material and welding processes. The Shield Metal Arc welding process (SMAW) as shown in Fig. 2 has been widely used in the past since it was easy to use. However, it is strictly important to control the amount of hydrogen released by the flux because it can trigger cracks of weld and heat affected zone which are important points that can generate fatigue damages.

By using modern welding technology, Gas Metal Arc welding process (MAG) and FluxCored Arc welding process (FCAW) as shown in Fig. 3 and 4, respectively are now becoming very popular.

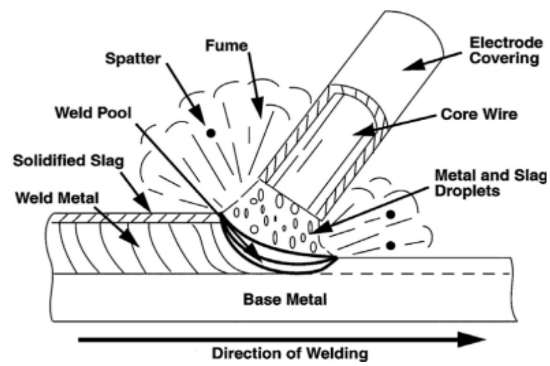

Fig.2: Shield metal arc welding process (American Welding Society, 1991)

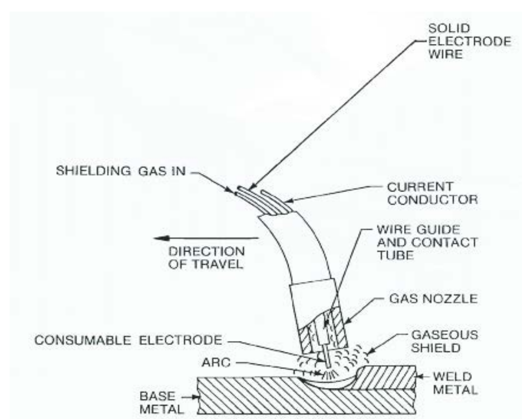

Fig. 3: Gas Metal Arc welding process (MAG)

The MAG and FCAW are widely used because of its faster-working speed, better control of hydrogen and less

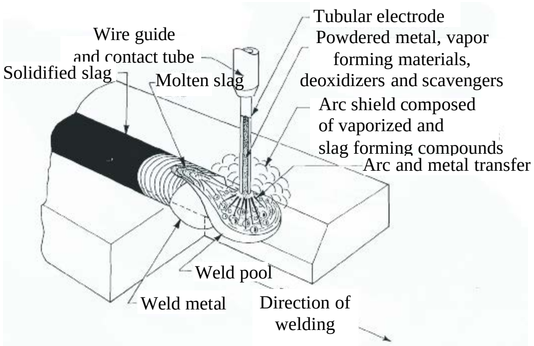

Fig. 4: Flux Cored Arc welding process (FCAW)

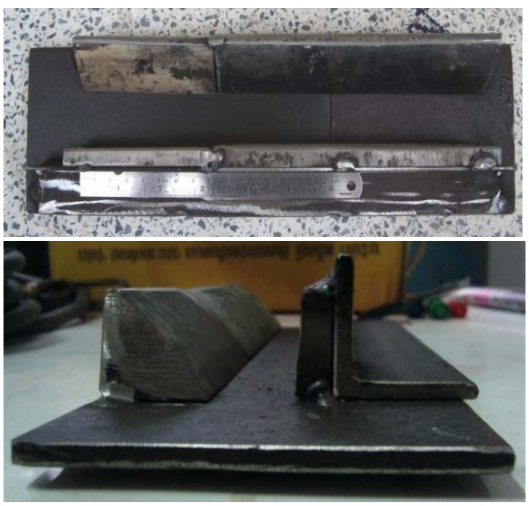

Fig. 5: Specimens before welding resurfacing

dependent on welder's skills. By choosing appropriate gas, for example Ar or Ar+CO_2 and other welding parameters such as welding current, welding voltage, welding speed and proper flow rate of gas (L/min), it can significantly improve mechanical properties of the weld. Types of metal transfer such as short circuit or pulse arc, also affect the penetration, bead appearance and mechanical quality of the weld. In addition, the MAG also causes much higher deposition rate than that of the SMAW due to the lesser loss of heat between the end of the welding rod and the work piece. Although, the MAG and FCAW are more complicated in terms of tools and equipment.

Knowledge of fatigue damages: When a material continuously received impacts, even if the force is lower than the ultimate strength of that material, cracks from fatigue can still form due to the changes of stress in operating machines. Damages from fatigue began with small cracks that cannot be seen by naked eyes, causing

Table 1: Parameter for welding etch process

Parameters	SMAW	MAG	FCAW
Electrode Types (AWS)	E11018-G H4R	ER110S-G	E110T5-K4H4
Preheat (°C) temperature	350	350	350
Electrode baking (°C for 1 h)	350	-	-
Temperature mixer gas flow rate (L/min)	-	12	12
Electrode diameter (mm)	4	1.2	1.2
Current (A)	145	205-220	210-230
Voltage (V)	26	25	25
Welding speed (Mm/min)	160	300	300
Heat input (kJ/mm)	1.06	0.81-0.87	0.87-0.97

additional stress. Cracks will expand rapidly which in turn will reduce the cross section area under stress. The reduction of cross section area increases the stress. Finally, the remaining cross section area will suddenly break a part. From the past experience, it can be concluded that fatigue failures are directly related to the welding part. The fatigue damage is the most important mechanical failure which accounted for 90% of all mechanical failure. The destruction from fatigue is extremely high, even though there are lots of new researches about it but the fatigue damage still occurred. The causes of damages such as: cyclic load: the load occurs with parts that deformed under cyclic force which has the change amplitude of stress and time; stress concentration area: the area that has high stress, resulted from the discontinuity of shape and cross section area of parts, producing the stress raiser; materials properties: each material has different properties which differences occurred due to their chemical compositions, types of microstructure and production processes such as forming and heat treatment. Tensile strength, yield strength, impact strength, hardness and fatigue strength are the changeable properties of materials.

Preparation of welding parts: Cut the Low Alloy Steels AISI 4340 specimens into squares with length of 25 cm, thickness of 1 cm and height of 2.5 cm. Then, cut another specimens into triangles with the dimensions 25 cm length, 2.5 cm height and 2.5 cm width. Assemble two shapes of specimens together as shown in Fig. 5.

Preparation of welding parts: Take the test specimens to preheat before welding at a temperature of 350°C and

Fig. 6: Shield metal arc welding process

Fig. 7: Gas metal arc welding process and flux cored arc welding process which are semiautomatic welding process

weld the specimens by each welding process as shown in Fig. 6 and 7 under given parameters as shown in Table 1. After finish welding, put the specimens to post weld heat treatment immediately at a temperature of 550°C for 1 h. Cool the specimens inside a furnace until their temperatures drop to room temperature which allows the preparation of fatigue strength test.

Fatiguet testing: Cut the specimens and leave out only the square weld metal shown in Fig. 8. After that, bring the weld metal to prepare specimens for fatigue testing. Lathe by using CNC machine to get the same size as in Fig. 9. Means stop testing when specimens exceed 1,000,000 rounds without a breaking of test specimen Fatigue testing is a test of fatigue strength with no incision. The test is performed by the changes of weight, where the values of bending moment and normal stress are shown in Table 2. Since the machine for fatigue testing has a limitation on weight which can be test between 5-40 kg; the reduction of specimens' diameter is needed in order to increase the weight of testing. There are six values of weight and two test specimens per one weight value and perform fatigue test as shown in Fig. 10.

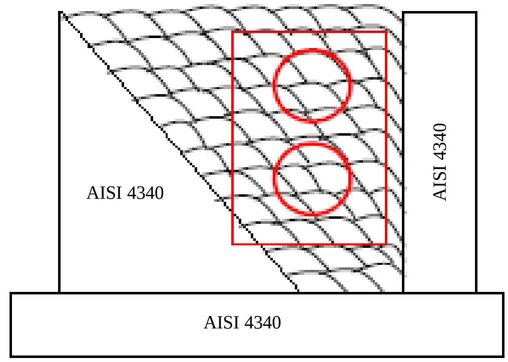

Fig. 8: Area that has been cut for preparing specimens for fatigue test

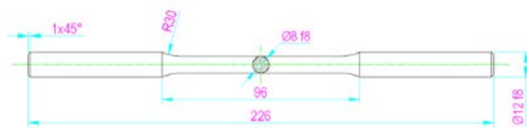

Fig. 9: Sizes of test specimens (unit: mm)

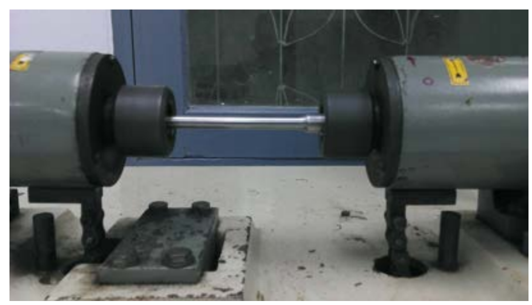

Fig. 10: Perform fatigue test

Table 2: Values of weight, bending moment and normal stress

Weight (kg)	Bending moment(Nm)	Stress (MPa)
35.2	1.760	350
40.2	2.010	400
50.3	2.515	500
60.3	3.015	600
70.3	3.515	700
80.4	4.020	800

RESULTS AND DISCUSSION

Results of examining fatigue strength of tested specimens by using X-ray: Since the number of used fatigue test specimens is only two pieces per one value of stress but according to ASTM E 739-91which uses six test specimens per one value of stress, it is therefore essential to check by using Gamma X-ray to get the perfect fatigue test before testing. The result of the test is shown in Table 3.

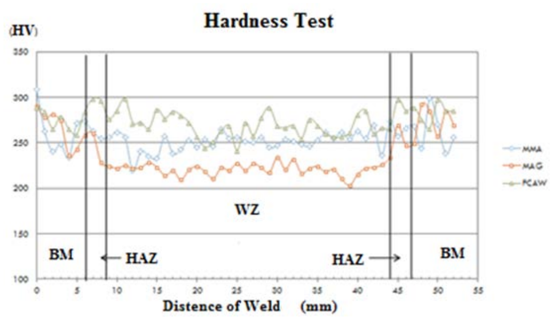

Fig. 11: Comparison graph of hardness values for each welding process

Table 3: The result of X-ray

Sample No.	SMAW	Interpretation MAG	FCAW1
1	No visual defect	No visual defect	Minor porosity
2	No visual defect	No visual defect	No visual defect
3	Lack of fusion, crack, porosity	Novisual defect	Minor Slag inclusion
4	Minor porosity	No Visual defect	Crack
5	No visual defect	No visual defect	No visual defect
6	No visual defect	Cluster porosity	No visual defect
7		Minor slag inclusion minor porosity	No visual defect88 No visual defect

Table 4: Values of stress and no. of round that cause damage

Stress (MPa)	MMA	Welding process MAG	FCAW	Base metal
300	-	-	6713160	-
350	1166063	1582570	1467630	-
400	203481	202039	804931	435609
400	185587	180793	815756	746380
500	52474	39854	105401	-
500	64230	184415	47150	107616
600	86168	3663	216760	85546
600	103394	1574	49008	-
700	4270	510	51210	13025
700	1377	895	15763	15763
800	-	-	1710	11831

Means stop testing when specimens exceed 1,000,000 rounds without a breaking of test specimen

Results of fatigue testing: The results of fatigue testing of specimens from the preparation of weld metal by using Shield Metal Arc (SMAW) welding process, Gas Metal Arc (MAG) welding process, FluxCored Arc (FCAW) welding process and Low Alloy Steels AISI 4340 are shown in Table 4.

Results of Vickers Hardness testing: The values of hardness of the one-layer welds will have higher values of hardness at the heat-affected area, when compare with the weld area and original metal. But in multilayer weld of all three welding processes, the value of hardness at the heat-affected area is slightly high, when compares with weld metal and original metal. In addition, the width of the heat-affected area is small because the heat of next layer will make bead deformation back to the previous layer. Hardness values of weld metal by shield metal arc welding process and gas metal arc welding process are slightly lower than the area of the original metal. The hardness value of weld metal by flux cored arc welding process is similar to the area of original metal shown in Fig. 11.

CONCLUSION

From this experimental study of shield metal arc welding process, gas metal arc welding process and flux cored arc welding process, it can be concluded that the value of fatigue strength of weld metal by flux cored arc welding process is similar to the original metal and it is more than that of the shield metal arc welding process and Gas metal arc welding process.

The weld repair by flux cored arc welding process prolongs the service life for 25% from repairing the original metal.The weld repair by Flux cored arc welding process can prolongs the service life for as much as 41% when compares to Shield metal arc welding process and prolongs the service life for as much as 97% when compares to gas metal arc welding process.

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