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Fatigue Life Estimates of Surface Welding X111-T5-K4 and E71T-1CH8/T-9M-D Flux Core Wire

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Abstract: This research aimed to investigate the fatigue life of surface welding, by using MIG-MAG welding process which the standard AWS A5.29/ASME IIC SFA-5.29 X111-T5-K4 and AWS A5.20/ASME SFA-5.20 E71T-1CH8/T-9M-D flux-cored wires were used. The method of this investigation consists of four steps: prepare specimens by using the C-Channel SCM 440 alloy steels, weld the specimens in the flat position, form the specimens into shapes by surface welding and find the fatigue strength of each specimen by using the rotating beam fatigue testing machine which complies with ASTM E739-91 standard. The result indicated that at 517 MPa fatigue stress, the specimen X111-T5-K4 gives the fatigue life of 97,896 cycles and its fatigue strength is approximately two times higher than that of the specimen E71T-1CH8/T-9M-D. The result of this research will be used as the preliminary information for evaluating the appropriate selection of welding wire and welding repair process that will be used in the maintenance program of cores in propeller shafts of the cut-stern Kolek, the local fishing boats of fishermen at the Coast of Songkhla Lake's community.

Key words: Surface welding, fatigue life, the cut-stern kolek boats, strengths, position

INTRODUCTION

The surface welding repair process of propeller shafts as shown in Fig. 1, has been developed continuously (Sitthipong *et al*., 2011), since the shafts are major machine components in power transmission systems of the cut-stern Kolek as shown in Fig. 2. Propeller shafts use driving forces from diesel engines as shown in Fig. 3, to move the boat hulls. These shafts exposed to cyclic torsional-flexural loadings; moreover, they had a stress concentration area. In addition, by using Eq. 1 to calculate Torsional loadings (T) which occurred on the shafts, the value of 34.121 Nm was obtained. Moreover, the results of using Eq. 2 and 3 gave the maximum bending stress (σ_{max}) and maximum shear stress (τ_{max}) of 474.67 Pa and 237.35 MPa, respectively. At any case, the bending stress factor sub of 2.0 and the shear stress factor sub of 1.5 (Lin *et al*., 2008) were used; the bending moment (M) had a value of 1491.12 Nm and the diameter and length of propeller shafts were 40 mm and 3.8 m, respectively:

$$T = 63.025\frac{P}{N}\,\text{lbs.in} \tag{1}$$

$$\sigma_{max} = \frac{16}{\pi d^3}\left[C_m M + \sqrt{(C_m M)^2 + (C_t T)^2}\right]\text{MPa} \tag{2}$$

Fig. 1: Propeller shaft

Fig. 2: Cut-stern Kolek

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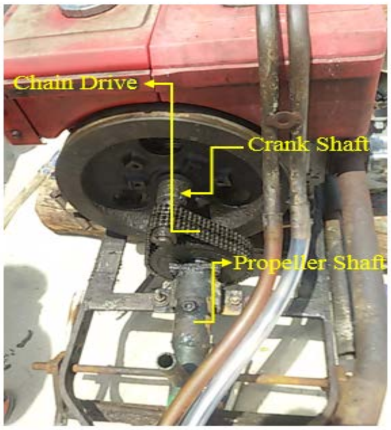

Fig. 3: Power transmission systems of the boats

Table 1: Chemical composition of SCM 440 alloy steel

Element	Content (w.t. %)
C	0.410
Cr	0.950
Mn	0.870
Mo	0.200
P	0.035
Si	0.220
S	0.040
Fe	97.220

$$\tau_{max} = \frac{16}{\pi d^3}\left[\sqrt{(C_m M)^2 + (C_t T)^2}\right] \text{MPa} \quad (3)$$

Substitute the bending stress and shear stress which are static loadings into Eq. 4 and 5 (Shigley, 1986), in order to convert them to the average stress and amplitude stress which are dynamic loadings. The values of the average stress and amplitude stress are 314 and 517 MPa, respectively:

$$\sigma_{m,s} = \sqrt{\sigma^2_{xm} + \sigma_{xm}\sigma_{ym} + \sigma^2_{ym} + 3\tau^2_m}\, \text{MPa} \quad (4)$$

$$\sigma_{a,s} = \sqrt{\sigma^2_{xa} + \sigma_{xa}\sigma_{ya} + \sigma^2_{ya} + 3\tau^2_a}\, \text{MPa} \quad (5)$$

where, σ_{xm}, σ_{ym} and σ_{xa} represent the mean stress and amplitude stress on x, y axis, respectively. The collected data reveals that the occurrence of fatigue stress on cores of propeller shafts gives the amplitude value of 517 MPa which exceeds the maximum fatigue strength of SCM440 steel (material for making the shafts). Its chemical composition is shown on Table 1. From the occurrence of fatigue stress, shafts enter fatigue mechanism; consequently, the shafts failed. The appearance of the fracture and its cracking surface are shown in Fig. 4. The failure of propeller shafts leads to the inefficiency of boats power transmission systems, causing engines to consume higher amount of fuel per unit distance. This causes the increasing in cost of fisheries; therefore, the removal and maintenance of propeller shafts are necessary. On the other hand, each time of maintenance results in the waste of time and opportunities for working; hence it is essential to find the method to prolong the service life of propeller shafts after they went through the welding repair process. By surveying the area for data collection of propeller shafts failure at Kaoseng fishing community and Bor-it fishing community -located on the Coast of Songkhla Lake, more than a hundred of cut-stern Kolek boats were found with the problem of shafts failure. However, the Kolek are still vital for inshore fisheries for several reasons. First, they are cheap. Second, their stability and mobility provide good tolerance to wind and waves, keeping them from tipping over. Third, their smaller size and lighter weight of hulls require lesser driving force and fuel. Finally, only 2-3 people are needed to operate the boat for fishing.

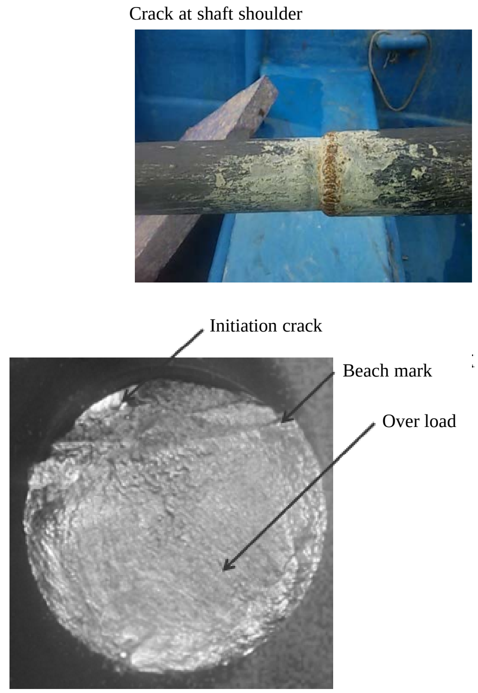

Fig. 4: Fracture's appearance

There are 2 levels of shaft failure. The first level that occurs often is the slight failure which a shaft can still be used for a period of time; however it will periodically illustrate a warning signal that indicates deterioration. The next level is the failure that produces the severe and immediate damages. For each boat, this level of failure occurs twice a year. Consequently, the boat will no longer be usable. When a shaft failed, welders will repair it by a resurface or build-up welding, using Shielded Metal Arc welding process (Sham and Liu, 2014). However, the result on the service life of repaired shafts was dissatisfied. In regard to the problem, this research intends to increase the effectiveness of prolonging the service life of propeller shafts by changing the repair welding process (Magudeeswaran *et al.*, 2008a, b; Sitthipong *et al.*, 2011). In addition, it also investigates on the fatigue life of surface welding, using MIG-MAG welding process with X111-T5-K4 and E71T-1CH8/T-9M-D flux-cored wires.

MATERIALS AND METHODS

Build up the weld surface by using X111-T5-K4 and E71T-1CH8/T-9M-D flux-cored wires First, cut the C-Channel SCM 440 alloy steels with 3 inches cross section into 30 pieces which each pieces has a length of 30 cm. After that, execute the surface welding on the inside of C-Channel by using MIG-MAG welding process as shown in Fig. 5 with 1.2 mm X111-T5-K4 flux-cored wires. Build up the weld surface to 20 mm as shown in Fig. 6. Each layer of weld beads is staggered and there is no pre or post-welding heat treatment. Then, switch the wires to E71T-1CH8/T-9M-D and continue the surface welding on the inside of C-Channel, using the same steps and processes for another 30 pieces. The controlled parameters of using MIG-MAG welding process with flux-cored wires are listed on Table 2.

FORM Testing specimens fromsurface welding of X111-T5-K4 AND E71T-1CH8/T-9M-D flux-cored wires: Bring all 60 specimens from X111-T5-K4 and E71T- 1CH8/T-9M-D flux-cored wires to cut and shape as 12.5×226 mm rectangle as shown in Fig. 7. Then, the result of 180 pieces of specimens is obtained. After that, use the CNC machine to lathe the specimens to have a diameter of 12.18 mm and a length of 226 mm; both ends drop off the shoulder of by 45° and 1 mm. At the length of 65 mm, measured from both ends it creates the curved shoulder with the radius of 30 as shown in Fig. 8. Finally, polish the specimens to have a smooth and glossy surface before testing. Details of the test specimens are shown in Fig. 9.

Test the fatigue strength of specimens built up by surface welding of X111-T5-K4 and E71T-1CH8/T-9M-D flux-cored wires: Take all 180 specimens resulted from MIG-MAG welding process and X111-T5-K4 and machine as shown in Fig. 10 which complies with ASTM E739-91 standard (Magudeesawaran *et al.*, 2008). The fatigue strength testing consists of the weight variations of 10 values; each weight values uses 9 specimens. This creates the cyclic torsional-flexural loadings to specimens until they break apart. E71T-1CH8/T-9M-D flux-cored wires to test for their fatigue strength by using the rotating beam fatigue testing.

Fig. 5: MIG-MAG welding process with flux-cored wires

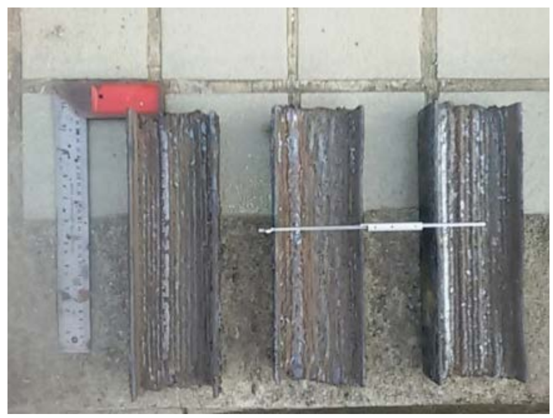

Fig. 6: Weld surface inside C-channel alloy steel

Fig. 7: Shaped specimens

Fig. 8: Specimens ready for testing

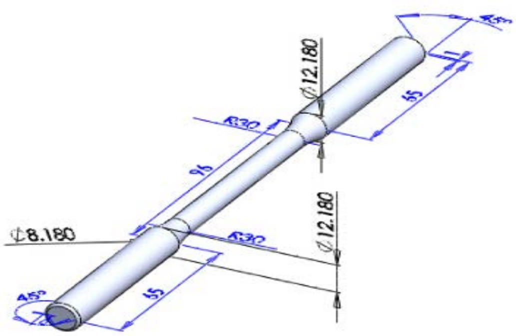

Fig. 9: Detail of specimens

Fig. 10: Fatigue strength testing machine

Table 2: Controlled parameter for MIG-MAG welding process with flux-cored wires

Parameter	Unit	Parameter Values of surface welding by using MIG-MAG welding process with flux-cored wires	
Types of electrode	-	X111-T5-K4	E71T-1CH8/T-9M-D
Mixer gas	%	80%Ar 20%COsub	80%Ar 20%COsub
Mixer gas flow rate	L/min	12	12
Diameter of wires	mm	1.2	1.2
Welding current	A	149	140
Welding voltage	V	21	24.5
Welding speed	mm/min	150	150
Heat Input	KJ/mm	1.00128	1.0976

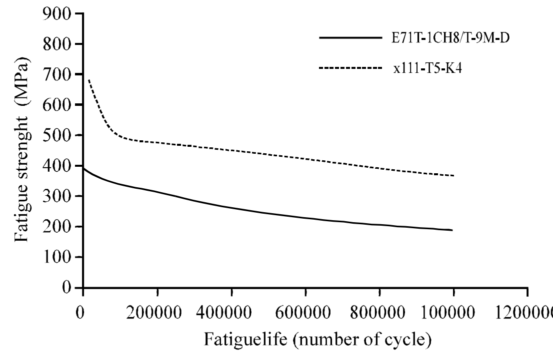

Fig. 11: S-N curve of surface welding

Table 3: Records of stresses and cycles that make specimens fracture

Stress for testing	Average cycle until fracture of X111-T5-K4 flux-cored wires	Average cycle until fracture of E71T-1CH8/T-9M-D flux-cored wires
150	Not fracture	Not fracture
200	Not fracture	953,476 cycle
250	Not fracture	483,576 cycle
350	Not fracture	80,048 cycle
400	800,972 cycle	7,432 cycle
450	455,839 cycle	Fractured at low-cycle
500	108,765 cycle	Fractured at low-cycle
600	44,832 cycle	Fractured at low-cycle
700	9,860 cycle	Fractured at low-cycle
800	Fractured at low-cycle	Fractured at low-cycle

Stop the testing at 1,000,000 cycles for each specimen; the specimen that can receive loadings more than 1,000,000 cycles will be reported as not fracture. In addition, the specimen that fracture before 1,000 cycles will be reported as fractured at low-cycle

RESULTS AND DISCUSSION

Record stresses and cycles that make specimens fracture on Table 3 and display their relationship on the graph shown in Fig. 11. By taking the 517 MPa of real stress value occurred on propeller shafts (caused by the driving forces of 11 Horsepower, horizontally opposed-piston diesel engines) to analyze with the data obtained from the experiment it is found that the use of MIG-MAG welding process with E71T-1CH8/T-9M-D flux-cored wires produce the fatigue life less than 1,000 cycles and give the maximum fatigue strength of 195 MPa. On the other hand, the X111-T5-K4 wires produce the fatigue life of 97,896 cycles and give the maximum fatigue strength of 371 MPa. The fatigue strengths and fatigue life were obtained by interpolation and extrapolation the data on Table 3.

CONCLUSION

The weld surface obtained from MIG-MAG welding process with X111-T5-K4 flux-core wires, under the controlled parameters, produces approximately two times higher maximum fatigue strength than that of the specimen E71T-1CH8/T-9M-D. Therefore, the

E71T-1CH8/T-9M-D flux-core wires should not be used for surface welding of propeller shafts, due to their insufficient strength of the weld surface to withstand the fatigue stress that occurred on the shafts. They will produce a very short service life of shafts after welding repairs which is not preferable in engineering economic principles.

RECOMMENDATIONS

The pre and post-heat treatment will reduce the residual stress in shafts; therefore, the service life of shafts will increase.

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