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Life Enhancement of Transverse Fillet Weld on Welds of HSLA S460G2+M using HFMI/PIT

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Abstract*: This study deals with the fatigue life enhancement of the transverse fillet weld on welds of 10mm thickness of the high strength low alloy steel (HSLA) S460G2+M which is treated using high frequency mechanical impact tool called pneumatic impact treatment (HFMI/PIT). Initially, the plate S460g2+M is prepared with 60^0 groove angles of butt joint and joined using gas metal arc welding (GMAW) with multi-pass welds followed by to weld the transverse attachment over the existing welds to produce a fillet weld on welds. Secondly, the HFMI/PIT treatment is applied on the fillet weld toe using 90Hz frequency, 6 bars of pneumatic pressure and 2 mm pin radius. Thirdly, the fatigue tests with constant amplitude loading are conducted on the untreated and treated specimens by applying 0.1 stress ratio and 55% to 75% stress loading from the yield strength of the base material. All fatigue data were evaluated based on international welding institute (IIW) commission XIII. It is found that the fatigue life of treated specimen is higher as compared with the untreated specimen. However, it is observed that an excessive heat input due to multi-pass welds has insignificant effect to the fatigue life of the untreated specimen.

***Index Terms*: Transverse Fillet weld on welds, HFMI/PIT, FAT class, S460G2 + M.**

I. INTRODUCTION

Fatigue failure of welded steel is extremely dangerous phenomena in the structural fabrication industry. Stress concentrations due to notches and welds geometry irregularity as well as the weld residual stress are broadly responsible for poor fatigue strength of weldment. The microscopic fatigue crack instigated from the sharp notches and eventually propagate when exposed to cyclic loading. Fatigue failure is unpredictable and cause severe damage to material [1].

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Over the year, countless fatigue studies were focused on the transverse fillet weld ranges from mild steels to high strength steel that frequently joined with a single weld [2] -[4]. Yet, the fatigue investigation on transverse fillet weld on welds is rarely mentioned by the researcher which is predominantly made with multi-pass welds.It is after all was a common welding practice by steel manufacturer and applicable for steel above 9 mm thickness. Many accepted welding procedures for this practice for an instant at the fabrication of the pressure vessel circumferential welds across the transverse seam welds and piping nozzle over the weldment of butt joint [5]-[6]. Though, it was acknowledged most metallurgist and welding practitioner worried about the effect of residual stresses and discontinuities due to the heat from multi-pass welds particularly after using dissimilar welding procedures of the two overlapping welds. It is known that, when several welds overlap a single-pass seam weld, the cooling rate of the welds will be diverse. Hence, the weldment that is anticipated to have an acceptable property due to a slow cooling rate could be inappropriate in the heat affected zone (HAZ). HAZ tends to be harder than base metal and weld metal which could lose some ductility [7]. Even though, the temperature in this region below its melting point, it is enough to change the microstructure. In addition, the volume of metallurgical destruction in the HAZ hinges on the capacity of heat input, the peak temperature, remoteness from fusion zone, cooling rate, the metal's thermal properties etc. [8].

Another problem to be considered is the divergence of chemical composition among the welds. Unusual heat input in the region of multi-pass welds effect in poor microstructure or excessive hardness [9]. In addition, the existing weld may be contain an imperfection such as internal defect, notches or undercut from a service that lead to crack initiation when exposed to dynamic loading that eventually a source of catastrophic fatigue failure [10]. Responding to this problem numerous companies tried to use various types of fatigue life enhancement such as the high frequency mechanical impact (HFMI). Among the HFMI tools that recognised by IIW are the Ultrasonic Impact Treatment (UIT), Ultrasonic Peening Treatment (UPT), High-Frequency Hammer Peening (HFHP), High-Frequency Impact Treatment (HiFIT) and Pneumatic Impact treatment (PIT) [11-15]. The operating procedures of these tools are quite similar, but dissimilar in term of consistency. Its vital function is to convert the tensile residual stress to compressive residual stress to extend the fatigue life of the fused component [16].

The efficiency of HFMI technology to increase the fatigue life of bonded steel were broadly discussed by many researchers [15], [17] - [22].

HFMI/PIT is the latest HFMI technology that invented with consistence mechanical impact on the treated region and eventually exceptional effect for fatigue life enhancement, especially for high strength steel [19]-[21]. Hence, the principal aims of this investigation is to conclude the fatigue life and the FAT class of the untreated and treated fatigue specimen of the S460G2+M. The fracture mechanism analysis of both fatigue specimens is also discussed respectively.

II. EXPERIMENTAL PROCEDURE

A. Review Stage Material

The material for fatigue investigation is HSLA S460G2+M with 10mm thickness, which is also addressed as offshore plate. It is broadly used in offshore platform, bridges and steel tower. The mechanical properties and chemical composition of this material are tabulated in Table 1 and 2.

Table. 1 The chemical composition of Filer wire ER80S-N1 and HSLA S460G2+M steel[21]

S460G2+M								
C %	Cu %	Mn %	V %	Si %	Al%	Cr %	Nb %	Ni %
0.19	0.11	1.62	0.10	0.6	0.032	0.10	0.012	0.09

Table. 2 Mechanical properties of HSLA S460G2+M steel[21]

HSLA S460G2+M	
t	t<16
Ys	460 MPa(min)
UTS	540-700 MPa
Ys/UTS	Max.0.93
CVN (- 40°c)	>60J transverse
Elongation. %	17%

B. Fatigue Specimen

The fatigue specimens of transverse fillet weld on welds is depicted in Figure 1. A multi-pass welds were made using GMAW on the 60° of groove angles of butt joint and then a transverse attachment is weld over the existing welds.

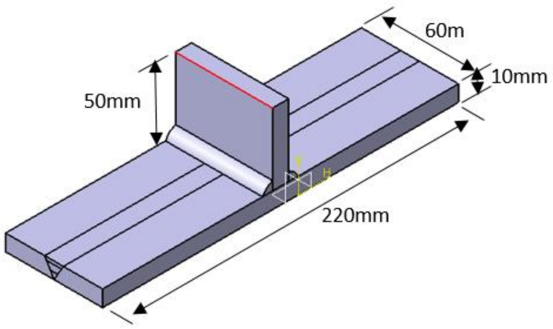


Fig. 1 Transverse fillet weld on welds

C. Welding Parameters

All fatigue specimens were joined using GMAW process. The combination of the parameters was obtained from welding procedure specification in [21] which is summarized in Table 3.

D. HFMI/PIT Treatment

Some of the fatigue specimens in Fig. 1 are treated with HFMI/PIT prior to the fatigue test. The treatment is applied on the both sides weld toes of the fillet weld using 2 mm pin diameter, 90Hz and 6 bars of pneumatic impact pressure. The treatment procedures were in accordance with IIW HFMI procedures which is illustrated in Fig. 2 [16].

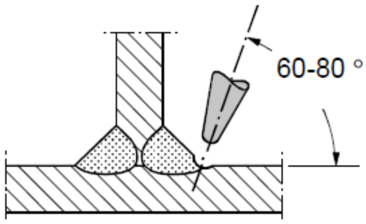


Fig. 2 HFMI/PIT treatment angles at the weld toe of the fatigue specimens

Table. 3 Summary of welding parameter for welding processes [21]

Item	: Description
Material	: HSLA S460G2+M
Groove angle	: 60˚
Roof face	: 1.5-2.5 mm
Roof gap	: 2.5 mm
Welding type	: GMAW
Shielding gas	: 80% Ar + 20% CO_2.
Filler metal	: ER80S-Ni1
Current and voltage	: Root = 90-100Amp, 18-22 V : Hot pass = 180-230 Amp, 18-22V : Capping = 180-230 Amp, 18-22 V

E. Fatigue Test

The fatigue tests were directed by means of constant amplitude loading in Instron fatigue machine 250kN. The fatigue loading was 55% to 75% of the yield strength of the base metal. There are overall 18 pieces of fatigue specimens classified as an untreated and treated specimen. The fatigue test data were evaluated an accordance with IIW commission XIII.

III. RESULTS AND DISCUSSION

A. S-N Curve Comparison

The comparison of fatigue life S-N curve between untreated and HFMI/PIT of the transverse fillet welds on welds are presented in Figure 3.

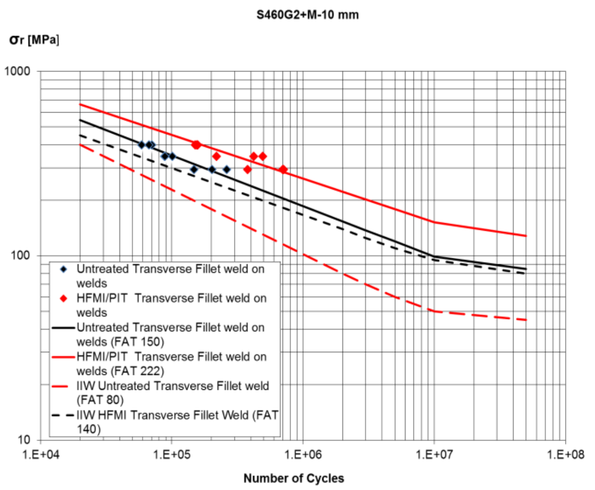


Fig. 3 SN-curve of the transverse fillet weld on welds of HSLA S460G2+M

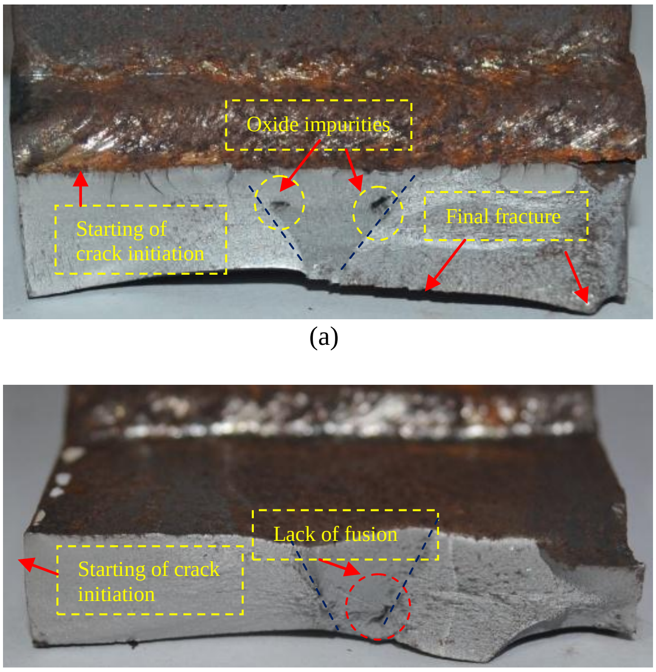
Based on the diagram in Fig. 3, it is found that the HFMI/PIT transverse fillet weld on welds specimen attained high fatigue life as compared with the untreated specimen. It's obtained 222 MPa of FAT class while the untreated obtain 150 MPa which is about 48% increments or equivalent with 1.48 bonus factor increments from the untreated specimen. FAT class is the fatigue design strength at two million cycles. Even though, the fatigue specimen was welded with multi-pass welds before the transverse weld attachment, it shows that HFMI/PIT treatment has a significant effect to the fatigue life of the specimen. The HFMI/PIT treatment method eliminate the stress concentrations around the fillet weld toes and the same time induced a compressive residual stress in the treated region which has increased the lifespan of the weld. However, another factor such as the quality of the weld and welder skill also contributed to the increments of the fatigue life. The FAT class of the fatigue test specimens and the IIW design recommendation for transverse fillet weld is summarized in Table 4.

Table. 4 Summary of FAT class fatigue strength increment

Transverse Fillet weld on welds	Value
Untreated FAT class (MPa)	150
HFMI/PIT FAT class (MPa)	222
IIW-Untreated FAT class (MPa)	80
HFMI FAT class (MPa)	140
Bonus increment factor (untreated vs HFMI/PIT)	1.48
% different untreated & HFMI/PIT	48%

B. Fracture Surface Analysis

Fracture surface analysis was conducted on the untreated and HFMI/PIT broken fatigue specimens to conclude the fracture mechanism of fatigue failures which could be relate to the lifespan of the specimen. The untreated and treated specimens are shown in Fig. 4.



(a)

(b)

Fig. 4 Fracture surface of the untreated (a) and HFMI/PIT transverse fillet weld on welds (b)

Based on the Fig. 4(a), it is seen that the fatigue crack initiation was started at the weld toe of the transverse fillet weld on welds specimen. An oxide impurities are also spotted in the region of the groove weld. Basically the oxide impurities due to the improper cleaning method during the progression of multi-pass welds. It is difficult to control the formation of internal weld defect in multi-pass welds processes [9]. This internal weld defects decreased the lifespan of the bonded joint. Thus, it is understood why the untreated fatigue specimen acquired lower fatigue life as compared with the HFMI/PIT specimen. However, another aspect that could be considered also is a HAZ region in the multi-pass welds, which is also reducing the lifespan of the welded joint.

The fracture surface of the HFMI/PIT specimen is shown in Fig. 4(b), it is found that the fatigue crack initiation was started at the right hand side of the base plate of the specimen which is distant from the fillet weld. This phenomenon is due to the HFMI/PIT eliminating the stress concentration around the weld toe that forbid the fatigue crack initiation. Compressive residual stress induced by the HFMI/PIT also prevent the crack initiation on the treated region. Thus, fatigue crack initiation was shifted to another location which is at the stress concentration around the base metal. Even though, it is found a lack of fusion on the groove weld it is less influence of the lifespan of the HFMI/PIT treated specimen due to isolated from the fillet weld of the specimen. From this examination, it is clear why the HFMI/PIT specimen acquired high fatigue life as compared to the untreated specimen.

IV. CONCLUSION

HFMI/PIT treatment has a huge benefit to the improvement of lifespan of the transverse fillet weld on welds due to the extensive increment of fatigue life and FAT class as compared with the untreated specimen. Multi-pass welds caused unexpected internal weld defect which is influencing the lifespan behaviour of the transverse fillet weld on welds of HSLA S460G2+M.

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