An Experimental Investigation on Fatigue Properties of AA3003-H14 Aluminum alloy Friction Stir Welds

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ABSTRACT

AA3003-H14 aluminum alloy plates were welded by friction stir welding and TIG welding. Fatigue properties of the welded joints were evaluated based on the superior tensile properties for FSW at 1500 rpm rotational speed and 80 mm/min welding speed. However, there is not much information available on effect of welding parameters with evolution of fatigue life of friction stir welds. The present study experimentally analyzed fatigue properties for base, FSW, and TIG welds of AA 3003-H14 aluminum alloy. Fatigue properties of FSW joints were slightly lower than the base metal and higher than TIG welding.

الخلاصة

تم لحام سبيكة المنيوم نوع AA3003-H14 باستخدام طريقة اللحام الاحتكاكي بالمزج FSW وكذلك باستخدام طريقة اللحام بغاز التنكستن الخامل TIG . وقد تم دراسة خواص الكلال للملحومات و للمعدن الاساس، وبالنسبة لملحومات FSW تم اختيار افضل كفاءة لحام عند سرعة دورانية ١٥٠٠ دورة/دقيقة وسرعة لحام ٨٠ ملم/دقيقة ، و لعدم توفر معلومات كافية حول تأثير متغيرات لحام FSW على خواص الكلال تم في هذا البحث دراسة خواص الكلال لملحومات FSW ومقارنتها بالمعدن الاساس وبطريقة اللحام TIG وبينت النتائج من خلال معادلة العمر ان ملحومات FSW تمتلك خواص كلال اقل قليلاً من المعدن الاساس واعلى من ملحومات TIG .

Keywords: AA3003-H14 aluminum alloy, Friction stirs welding, Fatigue properties,

INTRODUCTION

Friction stir welding (FSW) is a solid state joining process suitable for joining aluminum alloys developed by The Welding Institute (TWI), UK in 1991 . The process consists of a spinning cylindrical pin with a stepped shoulder, which is pressed against the seam line of the two parts to be welded .As the pin rotates, it penetrates the plates inducing a plastic deformation and then translates along the weld line .The friction between the tool and the parts produces material stirring motion that results in the weld .Thus far, the FSW process has been successfully developed and applied in various cases, but the process itself is not yet fully understood [M. Awang, et al 2005]. Friction stir welding has been applied to metals with moderate melting points .Initially, FSW was applied primarily to aluminum alloys, which could be easily welded due to the relatively low softening temperatures of these alloys . Other relatively soft metals, such as copper, lead, zinc, and magnesium, have also been welded .In contrast, for a number of years it was difficult to weld ferrous alloys and other high softening- temperature metals due to the lack of suitable tool materials [Carl and Tracy 2007].

MIG welding is a flexible and productive method and is therefore widely used for welding aluminum alloys in shipbuilding . However, two disadvantages with MIG welding are the deformation of the base material and a decrease in the strength of the heat affected zone.

Other fusion welding techniques like TIG and plasma welding are also widely used . However, these methods have the same weakness as MIG welding .An alternative to other fusion welding methods is the recently introduced Friction Stir Welding technique [Helena and Leif Karlsson 2000, L. Fratini et al 2007,and Vladvoj et al 2005].

Welding parameters and stirrer geometry effect, and tool effect on FSW have been studied [D .Booth and I .Sinclair 2000, P. Cavaliere et al 2008, Mustafa Boz and Adem Kurt 2004]. The typical welding defects and welding material aspects and the Effect of Friction Stir Welding on Dynamic Properties of some aluminum alloys also have been investigated [Hua-Bin et. al 2006, Bogdan Radu et. Al 2007,and Tomotake Hirato et. al 2007]. For many applications, like aerospace structures, transport vehicles, platforms, and bridge constructions, fatigue properties are critical. Therefore, it is important to understand the fatigue characteristics of FSW welds due to potentially wide range of engineering applications of FSW technique. This has led to increasing research interest on evaluating the fatigue behavior of FSW welds, including stress–number of cycles to failure (S–N) behavior and Fatigue Crack Propagation (FCP) behavior [Eui I. Lim 2006, Lemmen et al 2009, Omar et al 2009, G. Padmanaban and V. Balasubramamian 2010, N .Jayaraman et. al 2002]. However; there is not much information available on correlation of welding parameters with evolution of defect-free weld.

In order to produce a defect-free weld the optimization of welding parameters is extremely important .In this investigation fatigue properties of 3003-H14 aluminum alloy was studied after determined the optimization values of rotational speed and welding speed to produce best welding efficiency.

EXPERIMENTAL SET-UP

Friction stir welds were produced in AA 3003 aluminum using different combinations of rotational and welding speeds, as shown in Table 1 .Alloy AA 3003 is a non-heat-treatable Al-Mn alloy 1.04%Mn, 0.4%Fe, 0.192%Si with good weldability/formability and very good corrosion resistance lead to applications such

as food and chemical handling, tanks, trim, litho sheet, pressure vessels, and piping.
A clamping fixture was utilized in order to fix the specimens to be welded on a milling machine, Fig. 2. The tool was made in X38 tool steel cylindrical pin d with the following geometrical characteristics: shoulder diameter equal to 22 mm, pin diameter equal to 7 mm and pin height equal to 2.8 mm.
Two aluminum plates were utilized as base materials: AA3003-H14. The sheet metals were received in 100 mm×150 mm, with 3mm thick plate.
Fatigue tests were conducted at room temperature and with a constant amplitude in tensile testing The load ratio R =(min stress/max stress) was -1 .The fatigue samples were in the as-welded condition without machining the weld top and root faces, Fig. 3.

RESULTS AND DISCUSSION

FSW made a sound joint without voids, cracks or distortion. Fig .4 shows the macrostructure of the welded joint. The tensile strength of FSW joints for AA 3003-H14 material was carried out. Tensile specimens had been examined at room circumstances conditions, Fig.5. Tensile results shown in Fig 6 . Optimum value obtained at 1500 rpm and 80 mm/min and the efficiency 89 % of the base metal Al 3003 H14.

In Figures 7 to 9, the fatigue properties of FSW weldments are presented and compared with, TIG welding, and base metal. All the tested samplesof FSW showed very good fatigue behavior .Welds in base material AA 30033 showed better fatigue properties, compared with TIG welds .The scatter was also larger for welds in TIG than for welds in FSW, Fig. 10
From measured strength levels it would therefore be expected that fracture would occur in the weld region .This is in good agreement with the metal, equiaxed microstructure in the center of the nugget zone .It was difficult to predict where to expect fracture in AA 3003 from strength comparisons .
This investigation shows good fatigue properties for FSW samples Figure 8, and several investigations were conducted on the S–N curve behavior of FSW 3003-H14.
The Endurance limit of FSW weld at 2×10^6 cycles was lower than that of the base metal, i.e., the FSW welds are susceptible to fatigue crack initiation. However, the fatigue strength of the FSW weld was higher than that of TIG welds, as shown in Table 2. Typical S–N curves for FSW weld, TIG weld, and base metal of 3003-H14 are shown in Fig .10 .The finer and uniform microstructure after FSW leads to better properties as compared to fusion TIG welds. Surface quality of the FSW welds exerted a significant effect on the fatigue strength of the welds [N .Jayaraman et. Al 2002]. Overall, the fatigue results for FSWaluminum alloys are very encouraging.

The FSW joint has better mechanical properties than TIG joint, because of the differences between the two welding method should be considered. FSW is a solid state joining technology. The friction heat softens the welded material at a temperature less than its melting point. The softened material underneath the shoulder is also subjected to extrusion by the tool rotational. It is expected that this process will inherently produce a weld with relatively few residual stress and distortion. TIG is a fusion welding technology. The alloy is melt under high temperature during the welding process and then solidified. The weld of TIG joint is as-cast structure, which means work hardening disappears. Therefore the fatigue strength of TIG joints is lower than FSW joints [Juan Zhao, et al 2010].

CONCLUSIONS

The fatigue properties of 3003-H14 aluminum alloy friction stir welds in 3mm plates were studies in this paper. The main results can be summarized as following:
• AA 3003H-14 aluminum alloy was successfully joined without visual defects by friction stir welding under the following

parameters: 1500 rpm rotational speed and 80 mm/min welding speed with 89% welding efficiency.

• Good mechanical properties included fatigue properties of FSW joint are attributed to the well preservation of cold working microstructure.

• The fatigue strength of the FSW weld was higher than that of fusion TIG welds, the endurance limits were 52 MPa and 41 MPa for FSW joint and TIG joint respectively.

REFRENCES

Bogdan Radu et. al., “Aspects of the Material Flow during Friction Stir Welding of 5754 Al Alloy” , Institute for welding and Material Testing, Romania, IIW DOC., pp.1-10, 2007.

Brian M. Salerno, et. al., "Buckling Collapse Testing of Friction Stir Welded Aluminum", Technical Report, Ship Structure Committee, PP.7-9, 2009.

Carl D. Sorensen and Tracy W. Nelson, "Friction Stir Welding of Ferrous and Nickel Alloys ", Friction Stir Welding and Processing, ASM International, pp.111-121, 2007.

D .Booth and I .Sinclair, "Fatigue of Friction Stir Welded 2024-T351 Aluminium Alloy", Trans Tech Publications, pp.1-6, 2000.

Eui I. Lim, ” Fatigue Crack Propagation and Stable Tearing in Friction-Stir-Welded Aluminum Sheet”, ASIP, pp.1-29, 2006.

G. Padmanaban and V. Balasubramamian, "An experimental investigation on friction stir welding of AZ31B magnesium alloy, Int. J. Adv. Manuf. Technol.., vol.49, pp.111-121, 2010.

H. J. K. Lemmen et. al., ” Detailed strain field analyses of fatigue cracks in friction stir welded joints”, Aerospace structures and materials, pp.1-23, 2009.

Helena Larsson and Leif Karlsson, "Friction Stir welding of AA 5083 and AA 6082 aluminium", A welding review published by ESAB AB, Sweden, vol.54, No .2, pp.6-10, 2000.

Hua-Bin et. al., ”The investigation of typical welding defects for 5456 aluminum alloy friction stir welds”, Materials Science and Engineering A, pp.61-69, 2006.

Juan Zhao, et. al., "Comparative investigation of tungsten inert gas and friction stir welding characteristics of Al-Mg-Sc alloy plates", Materials and design, vol. 31,, pp. 306-311,2010

L Fratini, et. al., "Friction stir spot welding of AA6082-T6 :influence of the most relevant process parameters and comparison with classic mechanical fastening techniques", Proc .IMechE Vol .221 Part B :J .Engineering Manufacture, 2007.

M. Awang, et. al., " Thermo-Mechanical Modeling of Friction Stir Spot Welding (FSSW) Process :Use of an Explicit Adaptive Meshing Scheme". SAE International, PP.1-6, 2005.

Mustafa Boz and Adem Kurt, “The influence of stirrer geometry on bonding and mechanical properties in friction stir welding process”, Material and Design, vol.25, pp.343-347, 2004.

N .Jayaraman et. al., "Fatigue life improvement of an aluminum alloy FSW with low plasticity burnishing", Lambda Technologies, pp.1-10, 2002.

Omar Hatamleh et. al., “Fatigue Crack Growth of Peened Friction Stir-Welded 7075 Aluminum Alloy under Different Load Ratios” , Journal of materials Engineering and performance, 2009.

P. Cavaliere et. al., ” Effect of welding parameters on mechanical and microstructural properties of dissimilar AA6082–AA2024 joints produced by friction stir welding”, Material and Design, vol.25, pp.1-8, 2008.

Tomotake Hirato, et. al., “Influence of friction stir welding parameters on grain size and formability in 5083 aluminum alloy”, Materials Science and Engineering A, vol.456, pp.344-349, 2007.

Vladvoj Očenášek, et. al., "Microstructure and properties of friction stir welded aluminum alloys", Hradec nad Moravicí, pp.1-8, 2005.

Table 1: FSW process parameters variables

Sample No.	Weld speed (mm/min)	Rotational speed RPM
F1	20	1000
F2	20	1250
F3	20	1500
F4	20	2000
F5	40	1000
F6	40	1250
F7	40	1500
F8	40	2000
F9	60	1000
F10	60	1250
F11	60	1500
F12	60	2000
F13	80	1000
F14	80	1250
F15	80	1500
F16	80	2000

Table 2: Life equation and endurance limit of AA 3003 Aluminum alloy

Welding Process	Life Equation at 2×10⁶ Cycle	Endurance Limit (Mpa)
Base metal	$\sigma = 1168.5N_f^{-0.204}$	62
FSW	$\sigma = 773.42N_f^{-0.189}$	52
TIG	$\sigma = 617.68N_f^{-0.191}$	41

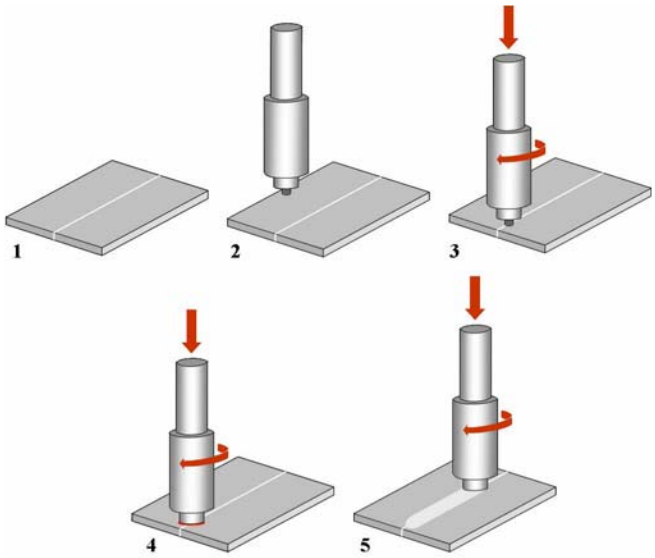

Figure 1: Steps of the FSW process [Brian M. et al 2009]

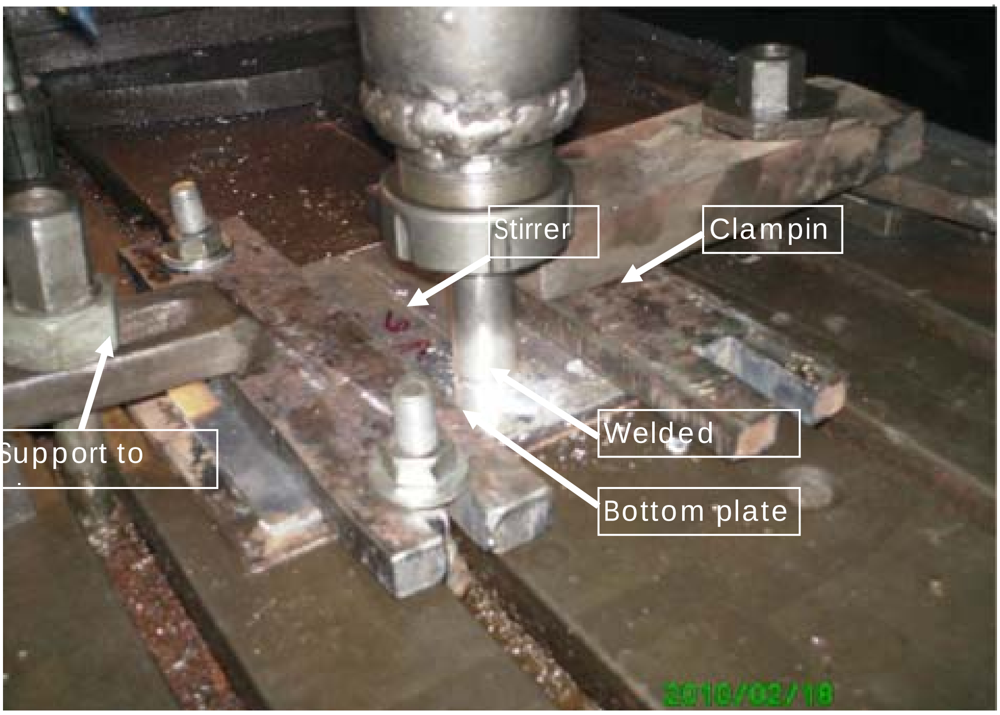

Figure 2: Experimental setup

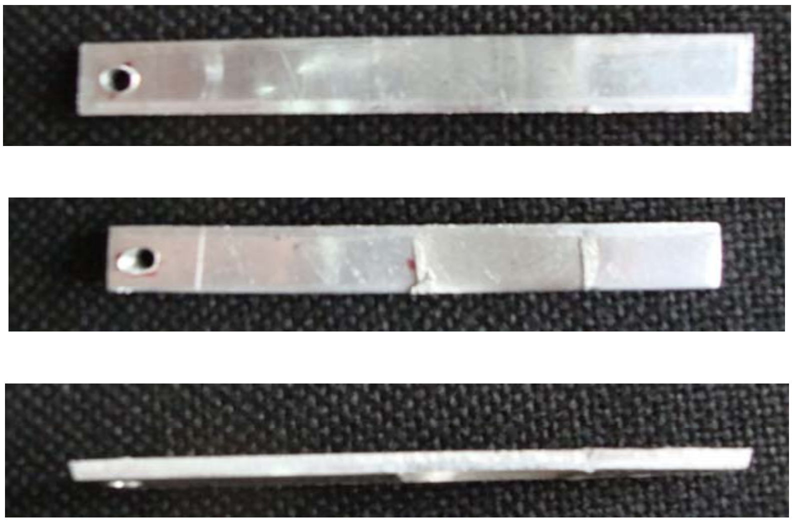
(a)
(b)
(c)

Figure 3: Fatigue sample of friction stir weld, a- Bottom surface of weld region, b- Top surface of weld region, c- Side view

Figure 4: Friction stir weld in 3 mm AA 3003, welded at 80 mm/min and 1500 rpm rotational speed.

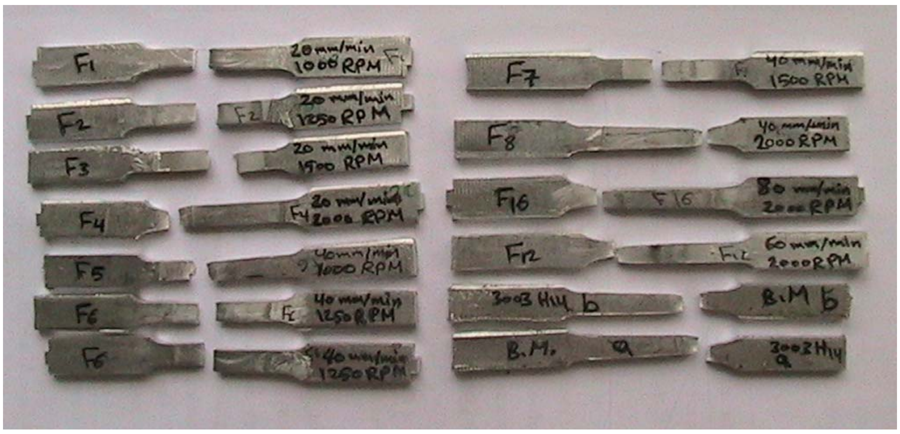

Figure 5: Some of tensile specimens after test

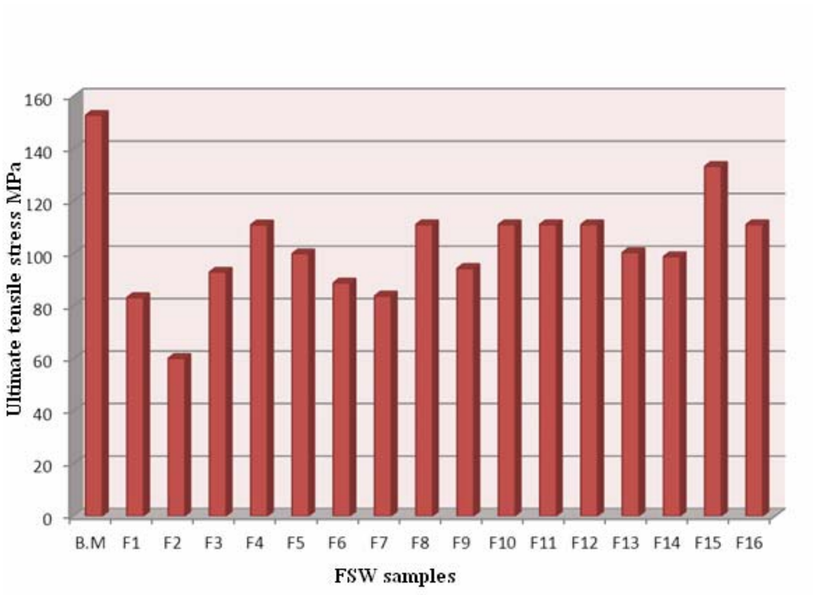

Figure 6: Tensile test results

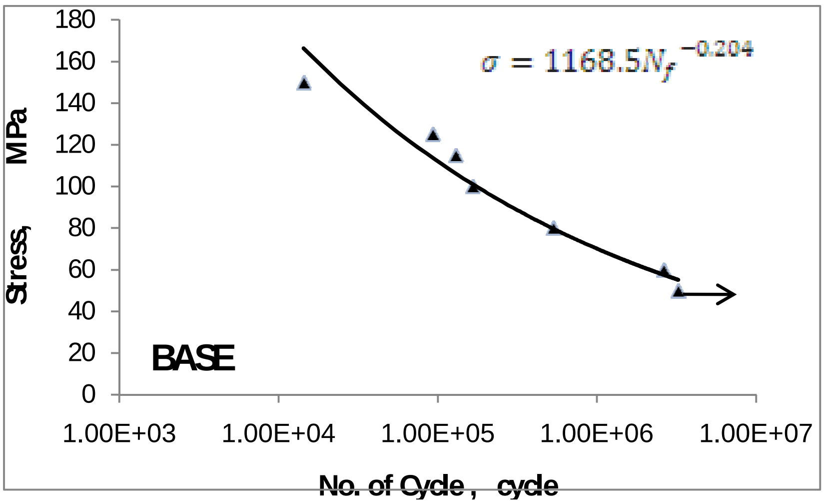

Figure 7: Base metal AA 3003-H14 S-N curve

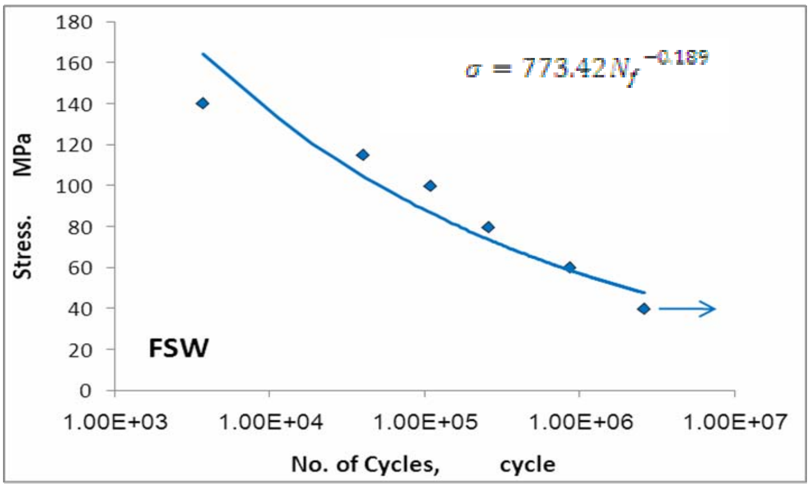

Figure 8: Friction stir welding AA 3003-H14 S-N curve

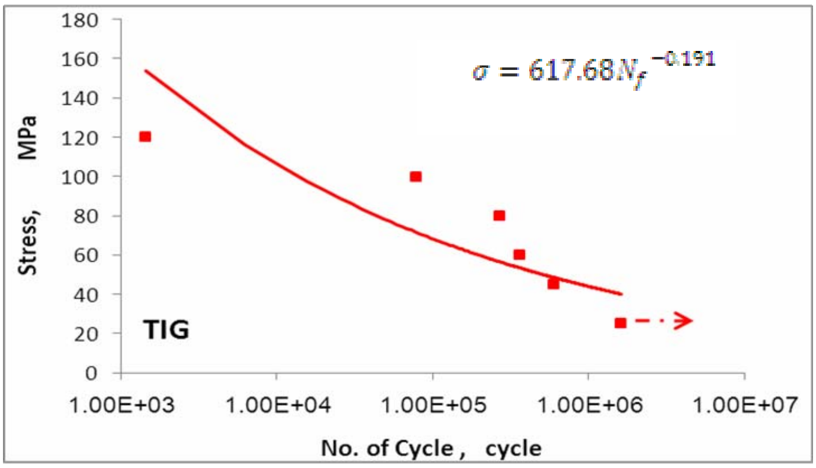

Figure 9: TIG welding AA 3003-H14 S-N curve

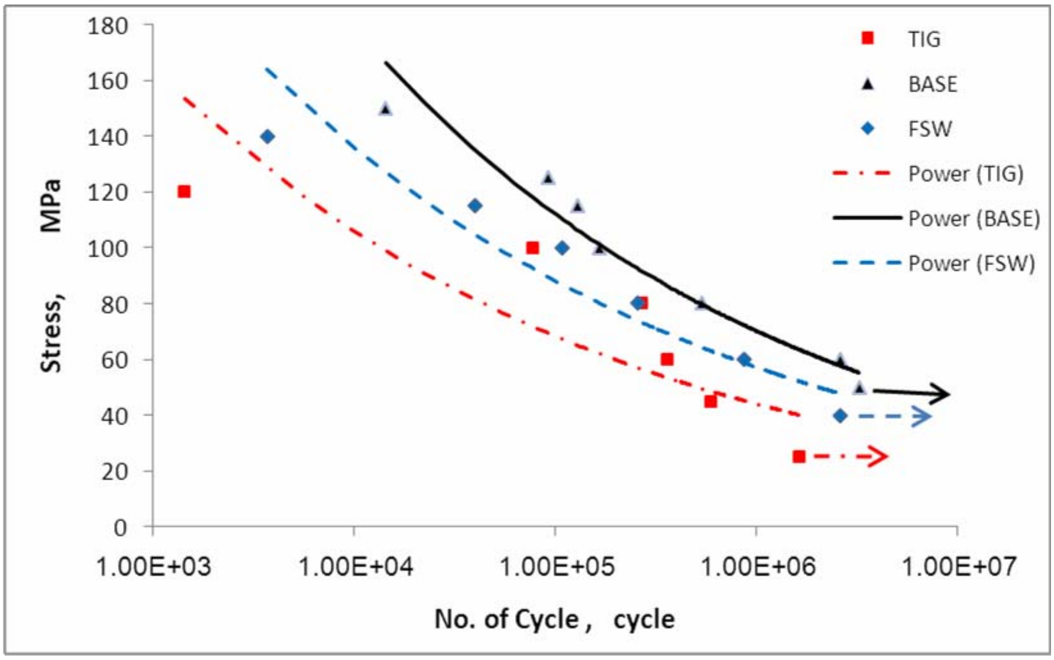

Figure 10: Comparison between base metal, TIG welding and FSW