

Fatigue Vibration Monitoring of Dissimilar Joints

Waluyo Adi Siswanto, Jeevana Jothi Ramakrishna

Abstract—Metal dissimilar joints are found in engineering applications and require special attention since the mechanical performance behaviours cannot be considered as comparable with those in similar joints. A current research has been conducted to investigate fatigue vibration life and response under constant loading of dissimilar joint materials. The investigation focusing on two dissimilar joint Stainless Steel to Mild Steel (SS-MS), with two benchmark comparisons of MS-MS and SS-SS. The defined three sets of specimens followed standard test of Tensile, Hardness and Fatigue. The monitoring of fatigue vibration was conducted by using laser Doppler; a non-destructive technique. Analysis of S-N and Fatigue Plots of Laser Doppler were then examined. It is found that dissimilar joint materials are quite different compared to similar joint materials due to stress singularity, residual stress and mechanical behaviour. Although dissimilar joints are applicable, conventional welding technique used in this research did not produce comparable mechanical properties and fatigue endurance as the similar joints. This research highlights the importance of considering special treatments of joining technique in regard to dissimilar joint metals. A comparison of S-N plots of similar and dissimilar joint materials are presented.

Keywords: Dissimilar Joint, Fatigue vibration, Laser Doppler

I. INTRODUCTION

Dissimilar material interfaces/joints can be found in numerous modern engineering and science fields, for example, adhesive bonded interfaces of two dissimilar

materials, microelectronics and also medical. Due to the different chemical, mechanical and thermal properties, dissimilar materials joining experiences challenges

Previous studies [1]-[3] reveal that dissimilar materials are difficult to be welded. This is because of the formation of brittle inter-metallic phases and wide difference in physical and mechanical properties. Besides, the melting points of these two materials are not same so it is not feasible for the two metals to melt at the same time and form an effective joint. Dissimilar joint can be welded if the melting points of the materials are nearly the same.

On the other hand, high thermal expansion coefficients differences also contribute in the difficulty which provokes thermal stresses during welding. For this consideration, TIG (Tungsten Inert Gas) is used in the present research. Metals also have certain fatigue life which will fail at a certain time but it can be prolonged with dissimilar metals because both have different fatigue failure and mechanical properties.

Fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. It is stated that a metal subjected to a repetitive of fluctuating stress will fail at stress lower than that on the application of load [4].

The process starts with dislocation movements, eventually forming persistent slip bands that nucleate short cracks. The greater the applied stress, the shorter the life. It also found that with increasing loading velocity, displacement to failure decreases for all the joint samples [5].

Fatigue life often decreases in a metal because of many factors. Magnitude of stress is one the factor which is a location in an object where stress is concentrated. An object is strongest when force is evenly distributed over its area so a reduction in area results in a localized increase in stress.

A material can fail when a concentrated stress exceeds the material's theoretical cohesive strength. Magnitude of stress is caused of part geometry such as when the shapes are sharp corners, holes and changes in cross sectional area of the object.

The current high temperature design guidelines do not distinguish dissimilar welds from similar welds and treat the weld effects in the same fashion by taking stress concentration factors [6].

The objectives are to study the fatigue vibration on a type

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dissimilar joint of stainless steel (SS) and mild steel (MS) by looking at the relationship between fatigue vibration responses, joining materials on the fatigue behaviour.

II. RESEARCH APPROACH

This research is conducted to obtain a fatigue life of dissimilar joint between stainless steel (SS) and mild steel (MS). For comparison purpose, the welded joints is not only prepared for stainless steel (SS) and mild steel (MS), but accompanied by SS to SS and MS to MS.

The tests involved are tensile test, hardness test, microstructure testing in obtaining the microstructure before and after welding and also fatigue test. A number of specimens are prepared for testing purpose, as listed in Table 1. For the fatigue test preparation, 6 sets of specimens are prepared as an average result required. Other tests only one specimen is sufficient.

Table 1: Testing specimens.

Mechanical test	Specime n	Number
Fatigue Test	SS-MS	6
	SS-SS	6
	MS-MS	6
Tensile Test	SS-MS	2
	SS-SS	2
	MS-MS	2
Microstructure	SS-MS	1
	SS-SS	1
	MS-MS	1
Hardness Test	SS-MS	1
	SS-SS	1
	MS-MS	1

The specimens are in cylindrical shape (rod), as illustrated in Figure 1. The joints are welded using Tungsten Inert Gas (TIG) welding. This method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds.

To get a better surface finish after welding, grinder and sand paper are used.

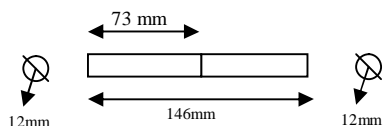


Figure 1: Dimension of specimen.

In high-cycle fatigue situations, materials performance is commonly characterized by an S-N curve, also known as a Wöhler curve. S-N curves are derived from tests on samples of the material to be characterized where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure. This process is sometimes known as coupon testing. Each sample specimen test generates a point on the plot though in some cases there

is a run-out where the time to failure exceeds that available for the test.

In order to measure the specimens when undergo fatigue testing, a non-contact portable digital vibrometer is employed. A “Polytec” Portable Digital Vibrometer (PDV) is used for non-contact measurement of surface vibrational velocities. This PDV is a compact, portable laser vibrometer with state-of-the-art design of optics and signal processing. It has frequency range from 0.05 Hz to 22 kHz and the handy PDV allows measurement accuracy. With the three measurements ranges which cover a velocity range of 0.05µm/s to 0.5m/s and with precise digital filters, PDV can adapt to nearly all applications in the acoustic frequency range. By focusing to the specimen, it captures the vibration of the twisting of specimen when load is applied.

The fatigue test is conducted on a revolving fatigue testing machine. In the revolving fatigue testing machine, a rotating sample which is clamped on one side is loaded with a concentrated force. As a result, an alternating bending stress is created in the cylindrical sample. Following a certain number of load cycles, the sample will rupture as a result of material fatigue.

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III. RESULT AND DISCUSSION

The vickers test is conducted to analyse the strength and toughness of the specimen. The Vickers test is same as the Brinell test which the intender is a diamond of 136° at the square base. The basic principle, as with all common measures of hardness, is to observe the questioned materials' ability to resist plastic deformation from a standard source. The unit of hardness given by the test is known as the Vickers Pyramid Number (HV).

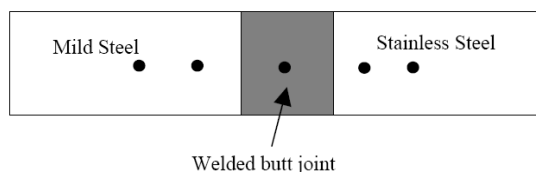


Figure 2: Nodes at specimen.

Table 2 shows the Vickers hardness value for three types of joints. The position of indentations done by the diamond indenter and the dimension of the specimen is shown in Figure 2 where five places are tested.

As it is expected the highest value of hardness is the stainless steel followed by mild steel. However, in the welded joint it clearly shows that the toughness of the material is reduced because of the atomic structure that bonds together was 'disturbed' by melting it and adding the filler metal.

Table 2: Hardness test results.

Number	Hardness value, HV		
	SS-SS	MS-MS	SS-MS
1	331.2	119.4	372.1
2	328.1	159.9	325.2
3	216.1	256.7	289.4
4	284.6	181.0	213.8
5	312.5	108.9	195.9

For the tensile test, the results are shown in Figure 3, the true stress versus true strain. The dissimilar joint is labelled as MS-MS with triangular marks. For comparison purpose, the result of similar joints of SS and MS are drawn in the same plot.

The chart shows that stainless steel and stainless steel joint has the greatest ultimate strength where it is the maximum strength that a metal can endure. It has the longer elastic region because stainless steel has higher hardness compared to mild steel, up to point of specimen necking and failure.

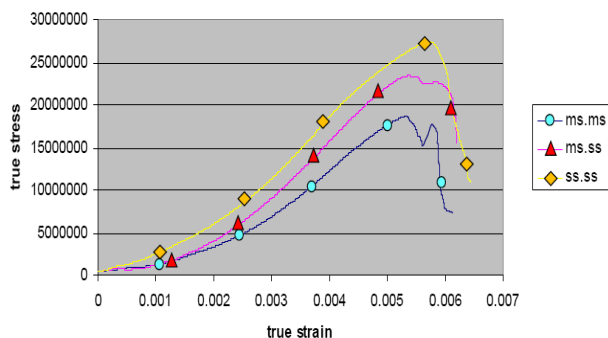


Figure 3: σ_{true} VS ϵ_{true}

During the fatigue testing, monitoring using Portable Digital Vibrometer (PDV) is also conducted.

Figure 4, Figure 5 and Figure 6 shows S-N curve line for SS-SS, SS-MS, and MS-MS joints. The best joint for fatigue vibration response is stainless steel joint compared to other joints because it can endure more cycles before it fails although it has same stress. Mild steel and stainless steel (SS-MS) joint is the unprofitable joint in this experiment because it fails faster as shown in Figure 7. This is because for this dissimilar joint, mild steel is the base of

the specimen where when fatigue is done, the fracture happens at base not at the welding. The comparison between the stainless steel similar joint and without the joint is also shown in the graph. It shows that stainless steel that is welded with filler metal and using TIG welding is stronger than a plain stainless steel without welding.

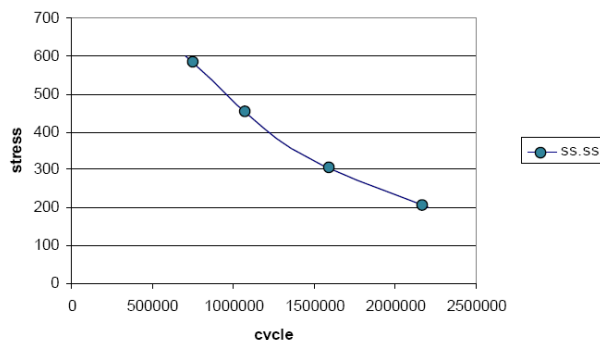


Figure 4: S-N curve for SS-SS.

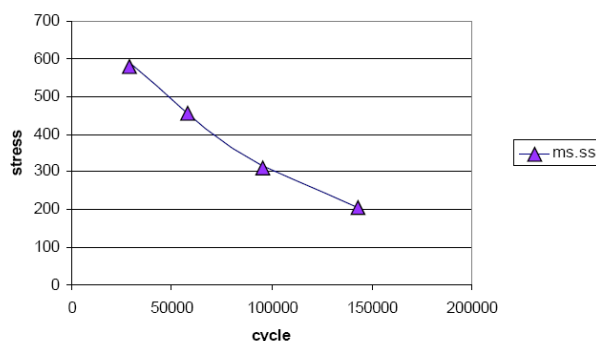


Figure 5: S-N curve for MS-SS.

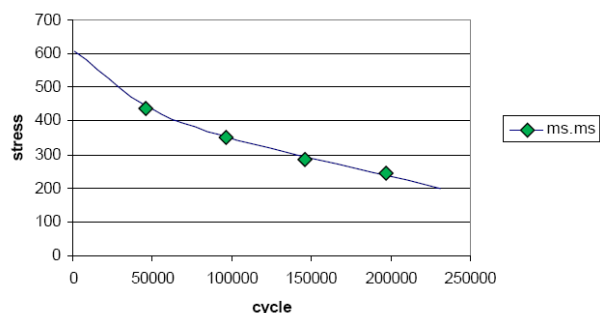


Figure 6: S-N curve for MS-MS.

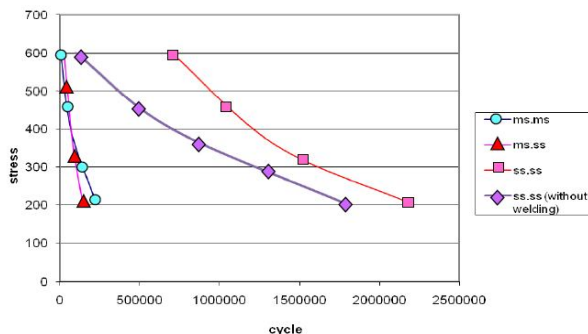


Figure 7: S-N comparison.

Portable Digital Vibrometer detects fracture whenever starts developing indicated by relatively high vibration. This is the resonance condition of the structure. Visible fracture can also be indentified in the structure.

A typical of vibration of SS-MS at 300N is shown in Figure 8 when a fracture identified in 150000 cycles.

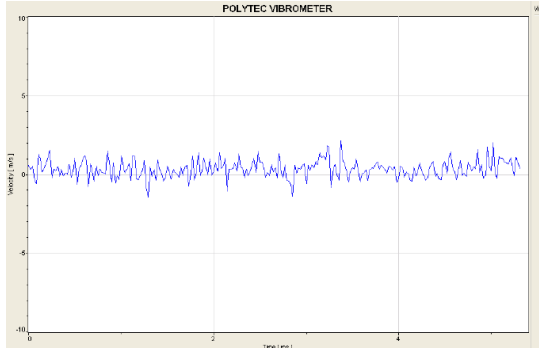
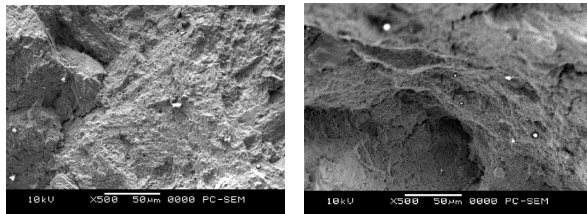


Figure 8: Vibration (velocity)

The microstructure after the welding is smooth for similar joints. For dissimilar joint of mild steel and stainless steel, the surface is not that smooth compared to the similar joint. Two different kinds of material are not fully merged in the welding process. The formation of brittle intermetallic phases can be seen and wide difference in physical and mechanical properties.

After fatigue the microstructure of dissimilar joint shows a brittle structure as depicted in Figure 9(b), if it is compared with that of before fatigue, shown in Figure 9(a).



(a) Before fatigue

(b) After fatigue

Figure 9: MS-SS welding.

IV. CONCLUSION

Dissimilar joint of Stainless Steel (SS) and Mild Steel (MS) has shown its weakness in mechanical properties.

In tensile testing, it shows a better tensile performance compared with the similar joint of MS-MS, but cannot reach comparable performance with SS-SS. The longer elastic property has shown in hardness test that in the welding section is softer.

The microscopic observation clearly shows that TIG welding dissimilar joint cannot combine uniformly the different materials, resulting a brittle and rough structure.

In a cyclic loading, the dissimilar joint performance of endurance. The dissimilar welding section is very critical. Compared to other similar joint welding sections, the dissimilar joint can be said that it is not recommended when dynamic or cyclic loads are involved.

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