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Fatigue Performance of Matching and Dissimilar Joints in Aluminium Alloys 5083-H111 and 6061-T651 after Fully Automatic Pulsed GAMW using ER5356 Filler Wire

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Abstract

The tensile strength and fatigue properties of Al5083-H111 welded with aluminium-magnesium alloyed ER5356 filler wire appeared similar to those of the base metal. This joint failed in the weld metal as a result of a slight reduction in hardness in the vicinity of the fusion line. However, the joints of Al6061-T651 similar and the dissimilar welds with Al5083-H111 displayed significant reduced strength and fatigue life due to lower hardness and tensile strength in the heat-affected zone.

Keywords: Aluminium alloy 5083-H111, 6061-T651, pulsed gas metal arc welding, ER5356 filler wire, dissimilar welds, tensile properties, fatigue properties

1. Introduction

Magnesium alloyed aluminium 5083-H111 has good weldability, with reduced sensitivity to hot cracking, and moderate strength. On the other hand, silicon–magnesium alloyed aluminium 6061-T651 has good formability (easy extrudability), machinability and adequate weldability, with medium strength. These alloys find their application in architectural structures and transport equipments, such as boats, ships, auto-body sheet and bridge, where Al5083 is often joined to Al6061 to produce welded structures such as complex I-beams and semi-hollow or hollow channels (Huskins *et al,* 2010, Dutta *et al,* 1990, Davis, 1998, Hatch, 1984).

The Pulsed Gas Metal Arc Welding (GMAW-P) is one of the welding processes to join aluminium and its alloys. It is an ideal and economic welding method for achieving good productivity, reducing the heat input and producing welds with good resistance in sea water, as confirmed by the separate studies of Czechowski, Praveen and Lean *et al*. (Czechowski, 2004, Praveen *et al,* 2005, Lean *et al,* 2003). However, the heat of welding affects the microstructure of the material in the immediate vicinity, thereby affecting weldment strength and fatigue performance.

The Fully Automatic FA-GMAW-P and geometrically dressed welds displayed improved mechanical properties in 5083-H111 welds, as shown by Mutombo and Du Toit (Mutombo *et al,* 2010).
Although data on the mechanical properties of magnesium alloyed and silicon-magnesium alloyed aluminium may be found in the literature, there is still not enough on the mechanical behaviour and fatigue performance of matching and dissimilar FA-GMAW-P welds of Al5083-H111 and Al6061-T651 alloys.

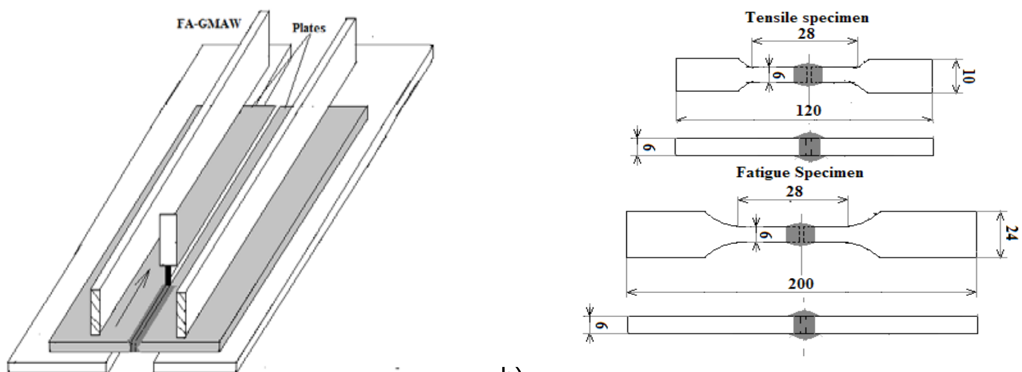
The present work investigated the tensile properties and fatigue behaviour of welded joints in Al5083, Al6061, as well as dissimilar joints between Al5083 and Al6061, using magnesium-alloyed ER5356 filler wire and the FA-GMAW-P process.

2. Experimental procedure

Flat sheets of 2000 mm long, 120 mm wide and 6.35 mm thick 5083-H111 and 6061-T651 aluminium alloys (chemical composition given in Table 1) were joined using the FA-GMAW-P process. The ER5356 (Al-Mg) filler aluminium alloy was used. In this process the filler wire and the welding torch were displaced automatically (Figure 1a). Plates were degreased and welded with a square butt edge preparation.

Table 1. Chemical composition of Al5083-H111 and Al6061-T651 alloys

Element %	*Al*	*Mg*	*Mn*	*Fe*	*Si*	*Cr*	*Cu*	*Zn*	*Ti*	*Others total*
5083-H111	REM	3.66	0.39	0.40	0.22	0.14	0.04	0.03	0.02	<0.001
6061-T651	REM	0.96	0.09	0.40	0.80	0.21	0.27	0.00	0.02	<0.01



b)

a)

Figure 1. a) FA-GMAW-P welding technique and b) Tensile and fatigue specimens

The 5083-H111 and 6061-T651 aluminium alloys were welded in the horizontal position using argon shielding gas. The pulsed FA-GMAW parameters are shown in Table 2.

Table 2. Pulsed gas metal arc welding process parameters

Parameters	*Arc voltage*	*Welding current*	*Wire feed rate*	*Wire diameter*	*Nozzle to plate distance*	*Travel speed*	*Torch angle*	*Gas flow rate*
Unit	*V*	*A*	*m/min*	*mm*	*mm*	*m/min*	*Degrees*	*ℓ/min*
FA-GMAW	20-23	133-148	6.1-7.6	1.2-1.6	15-20	0.4-0.6	60-80	19-28

Specimens were wet-ground, polished and then etched in respect to the ASTM standard E340 (ASTM International 2002), and thereafter examined using an optical microscope (OM). Vickers Microhardness tests were performed on polished samples, according to the ASTM standard E34 (ASTM International 2004). A loading of 10 gf and a dwell time of 10 seconds were set on the Vickers Microhardness Tester FM-700 equipped with HDPS-ARC ver.1.23 software. Hardness profiles from the fusion centre line of the weld metal (WM), through the heat-affected-zone (HAZ), to the base metal (BM) (dot lines, Figures 2a, 3a and 4a) were constructed for welded and unwelded specimens of 5083-H111 and 6061-T651 aluminium alloys. The machined specimens, schematically shown on Figure 1b, were wet-ground flush in the longitudinal direction to geometrically dress and/or remove all circumferential marks on welded and unwelded specimens. The tensile and fatigue tests were carried out in laboratory air, using an Instron testing machine. Tensile tests were performed, according to ASTM standard E8 ASTM (International 2004) at an Instron cross-head speed of 3 mm/min. The fatigue test ran at a frequency of 1Hz and in a symmetric tension-tension cycle (the stress ratio R = 0.125) to keep the crack opened. Depending on the quality of the weld, three to six specimens per amplitude stress were used to record the number of cycles to failure. The temperature varied between 17°C and 21°C and humidity levels changed between 35.7% and 70.6% RH. To evaluate the mechanical properties, unwelded and welded specimens of 5083-H111 and 6061-T651 aluminium alloys were collected for comparison. In order to determine the fatigue resistance, the Stress-Number of cycles (S-N) curve was constructed. The fracture surfaces were examined, using a stereomicroscope (SM) and scanning electron microscope (SEM), to reveal the primary crack initiation sites and mode of fracture.

3. Results and discussion

The FA-GMAW produced welds free from deep toe undercutting, whereas under filling and subsurface flaws, such as porosities and slag-inclusions were present in the welds (Figures 2a, 3a and 3b). A narrow HAZ, of about 2 mm, was revealed in the 5083-H111/ER5356 weldment (Figure 4c), while a wide HAZ (15 mm) appeared in the 6061-T651/ER5356 (Figure 6b).

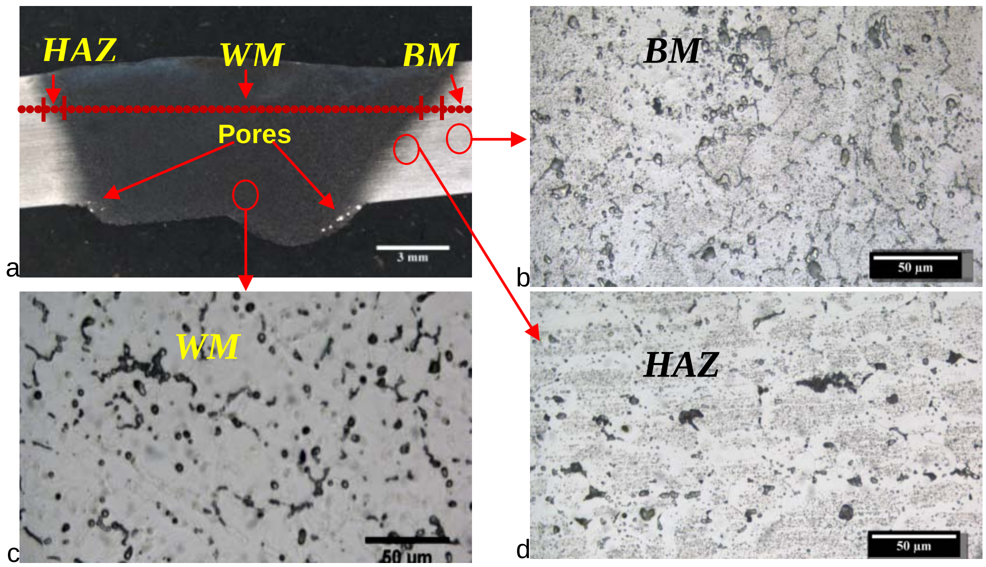


Figure 2. 5083-H111/ER5356 matching weld, a) undressed profile, b) BM microstructure, c) WM and d) HAZ microstructure

Coarse grains were revealed in the base metal of 6061-T651 (Figure 4d), 5083/ER536 HAZ (Figure 2d) and HAZ of 6061-T651/ER5356 matching and dissimilar welds (Figures 3b and 3d), while fine grains were observed in the Al5083-H111 BM (Figure 2b). The slight increase in grain size of the HAZ is the results of over aging in Al6061 BM and annealing in Al5083 BM as the effect of work hardening is totally lost when this alloy is exposed to a temperature above 348°C (Davis, 1998).

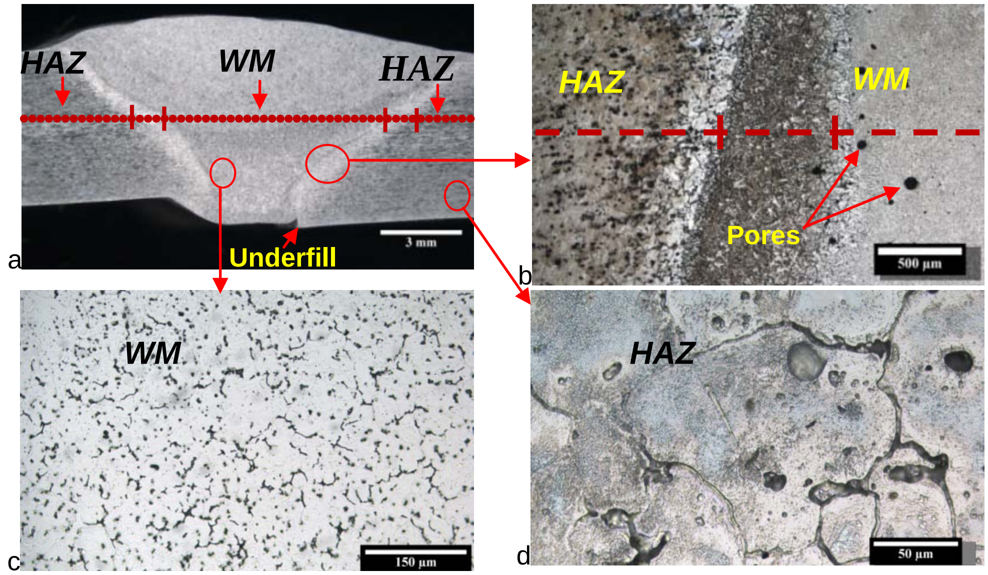


Figure 3. Al6061/ER5356 matching weld, a) 5083/ER5356 undressed weld, b) HAZ/WM interface, c) weld metal and d) HAZ microstructure

The dissimilar weld (Figure 4a) revealed two different joints, 5083/ER5356 and 6061/ER5356. Homogeneous structure and slight reduction in hardness and static strength is observed in Al5083 HAZ (Figures 4c, 5c and 5d), whereas heterogeneous structure and high degree of softening and lower mechanical properties had been noticed in Al6061/ER5356 joint (Figures 4b, 3b, 5c and 5d).

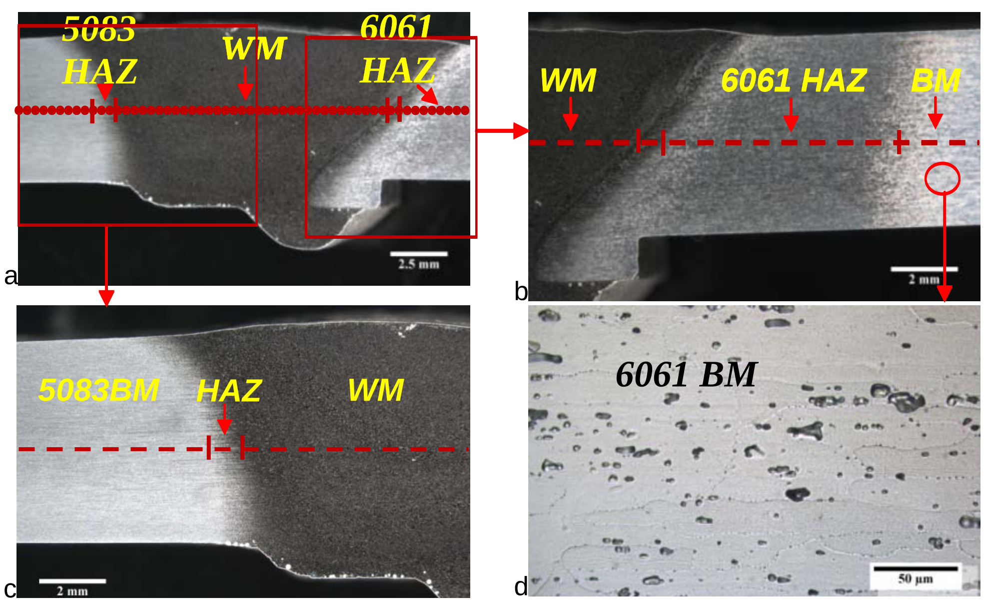


Figure 4. a) 5083/ER5356/6061 dissimilar weld, b) 6061/ER5083 side, c) 5083/ER5356 side and d) Al6061-T651 BM microstructure

The Al5083-H111/ER5356 weld exhibited similar mechanical properties to that of the unwelded 5083-H111 aluminium alloy in geometrically dressed weld condition (Figure 6b). However, the UTS in the similar or dissimilar weld is almost 60% of the base metal, and the 0.2% offset yield strength of the weld is about half of that of the base metal (Figure 4d).

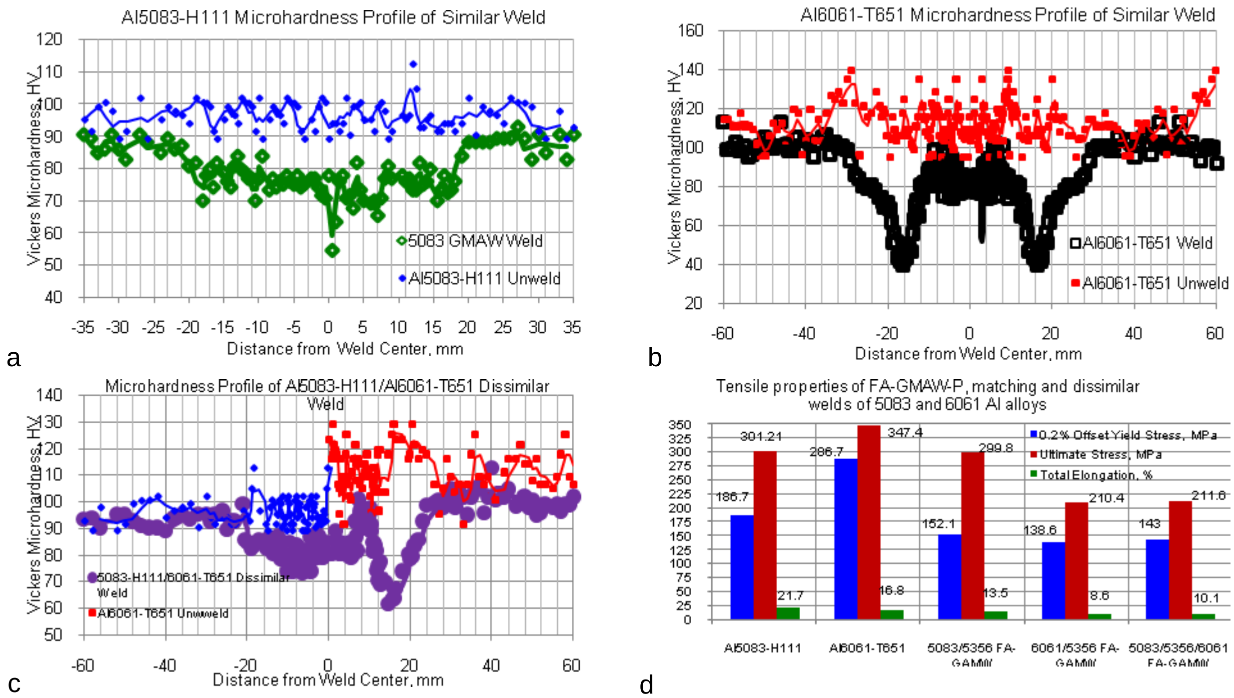


Figure 5. Hardness profile of a) 5083-H111/ER5356 similar weld, b) 6061-T651/ER5356 similar weld and c) 5083-H111/ER5356/6061-T651 dissimilar welds and d) their tensile properties

Geometrically dressed welds of Al5083-H111 ruptured in the weld metal region when pulled in tensile, as represented in Figure 6b. This is mainly due to the presence of porosities (Figures 6c and 7c) that reduce the yield strength of the Al5083 weld alloy, as represented on the graph of tensile properties (Figure 5d). However, failure occurred in the Al6061 HAZ of matching and dissimilar welds (Figure 6a) due to over aging of the base metal and high residual tensile stresses that are locked in the HAZ (Davis, 1998).

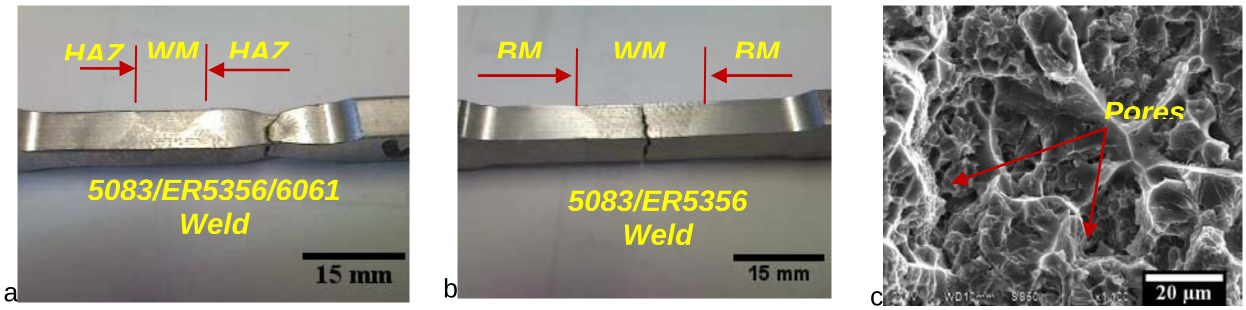


Figure 6. Tensile fracture in a)6061 HAZ, b) 5083 WM and c) brittle fracture in 5083 WM

The fatigue life of Al6061-T651/ER5356 similar weld and Al5083-H111/ER5356/Al6061-T651 dissimilar weld in laboratory air is sensibly reduced from that of Al5083/ER5356 weld as compared to the unwelded Al6061-T651 and Al5083-H111 alloys (Figure 7). Failure in unwelded specimens of Al5083-H111 and Al6061-T651 initiated at the free surface (Figures 8b and 9b) as a result of slip lines interacting with solute-rich second-phase particles, such as Mg_2Si, Al_3Fe, Al_3Mg_2 (Figures 8c and 8d). However, in Al5083/ER5356 the crack propagated from pores, as shown in the Figures 10d and 10c.

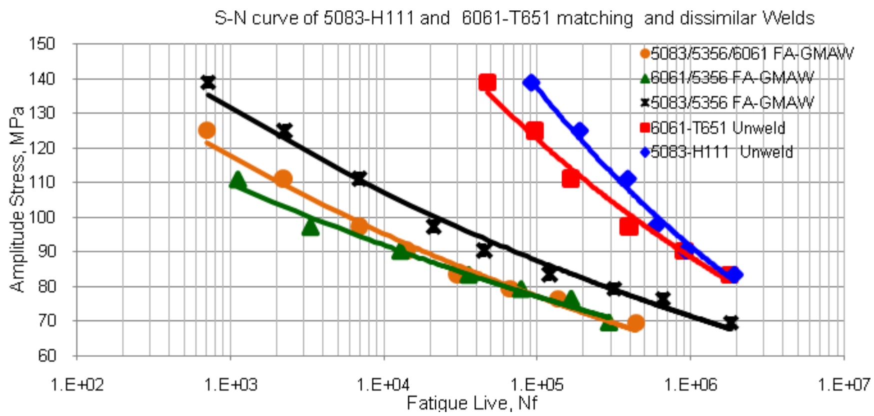


Figure 7. Fatigue performance of 5083-H111 and 6061-T651 matching and dissimilar welds

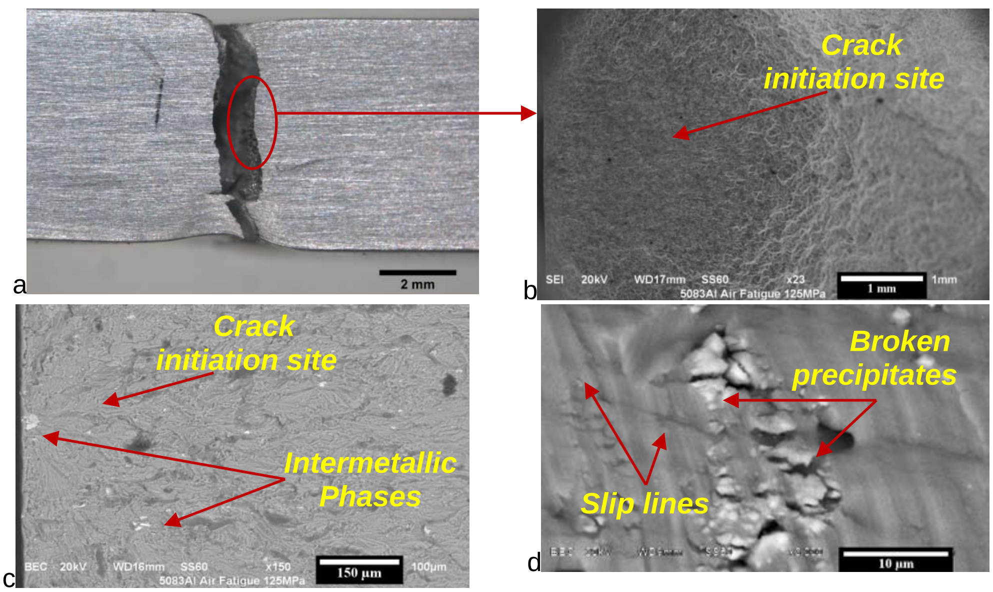


Figure 8. Failure of Al5083-H11, a) fractured specimen, b) crack initiation site, c) backscattered image of crack initiation site and d) initiation of crack from broken precipitates and slip lines

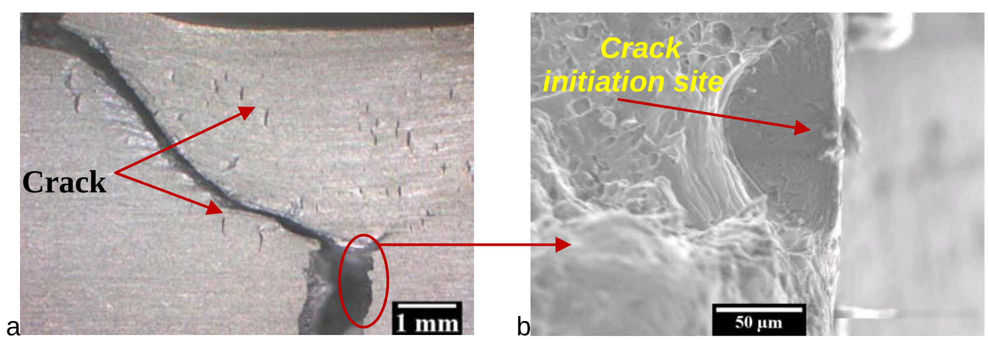


Figure 9. Failure of Al6061-T651, a) fractured specimen and b) crack initiation site

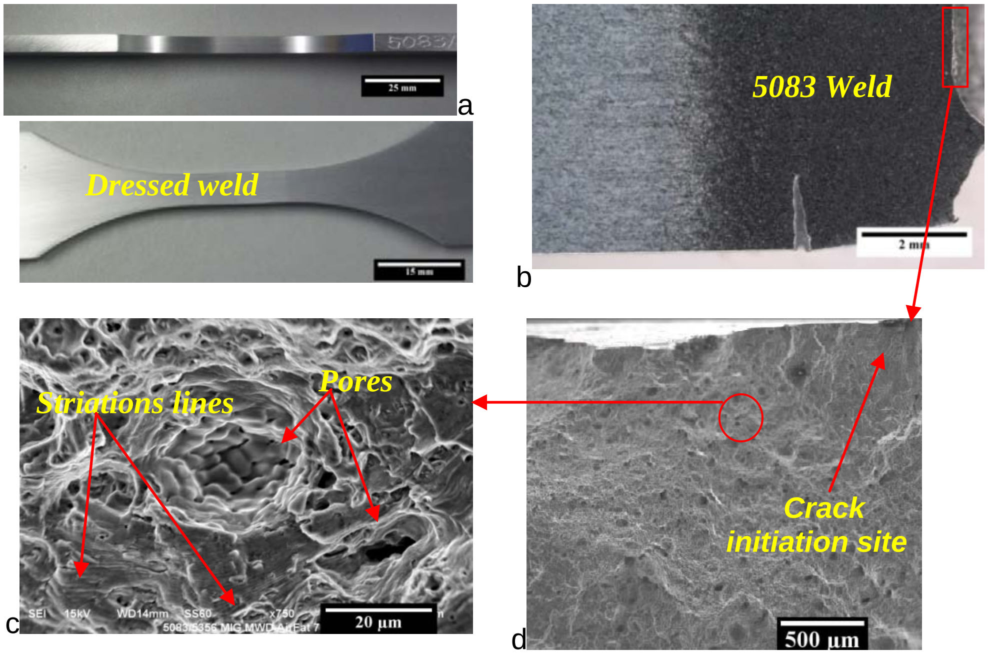


Figure 10. Fatigue fracture of Al5083/ER5356, a) dressed weld, b) fracture in the WM, c) pores on crack propagation area and d) crack initiation site

Most of Al6061/ER5356 welds failed in HAZ (Figure 11a). Cracks initiated from the free surface (Figure 11b) as a result of interaction between slip lines and precipitate-pulled-off sites (Figure 11c). This is due to the fact that the harder solute-rich second-phase particles contained in the softer Al6061 matrix are pulled off when cycling stresses are applied. Striation lines may also be observed on the fracture surface of Al6061 HAZ, as shown in the Figure 11d.

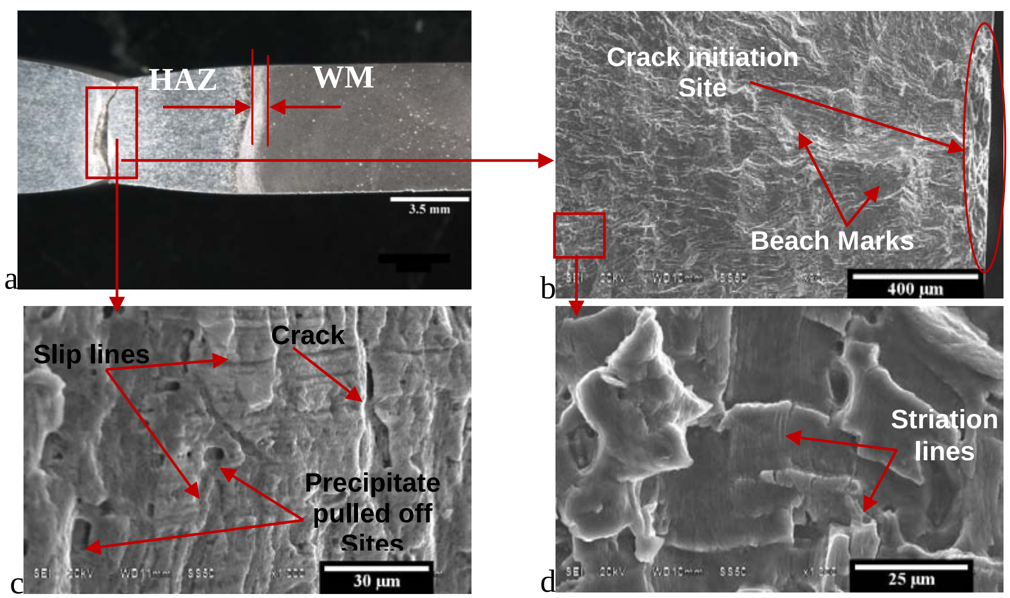


Figure 11. Fatigue failure of 6061/ER5356 weld, a) fracture in HAZ, b) crack initiation site, c) crack initiation from free surface and d) propagation of the crack

4. Conclusions

The fully automatic gas metal arc welding strongly affects the mechanical properties and the fatigue behaviour of 6061-T651 aluminium matching and dissimilar welds. Failure occurred in weld metal of 5083-H111 aluminium alloy, however the weld of 6061-T651 aluminium alloy failed the heat-affected zone. The fatigue life of 6061-T651 weldment sensibly decreased, due presumably to the softening and coarsening effect in the heat-affected-zone, as compare to the 5083-H111 weld and unwelded aluminium alloys.

5. References

Huskins, E.L., Cao, B. & Ramesh, K.T. 2010, "Strengthening mechanisms in an Al–Mg alloy", *Materials Science and Engineering: A,* vol. 527, no. 6, pp. 1292-1298.

Dutta, I. & Allen, S.M. 1990, "A calorimetric study of precipitation in commercial aluminium alloy 6061", *Journal of Materials Science Letters,* vol. 10, no. 1991, pp. 323-326.

Davis, J.R. 1998, *Aluminum and Aluminum Alloys*, 4th edn, ASM International, United States of America.

Hatch, J.E. 1984, "Aluminium: Properties and Physical Metallurgy" in *Aluminium: Properties and Physical Metallurgy* American Society for Metals, United State of America, pp. 242-242- 248, 253.

Czechowski, M. 2004, "Corrosion Fatigue of GMA Al-Mg Alloy", *Advances in Materials Science,* vol. 4, no. 2004, pp. 16-24.

Praveen, P. & Yarlagadda, P.K.D.V. 2005, "Meeting challenges in welding of aluminum alloys through pulse gas metal arc welding", *Journal of Materials Processing Technology,* vol. 164-165, pp. 1106-1112.

Lean, P.P., Gil, L. & Ureña, A. 2003, "Dissimilar welds between unreinforced AA6082 and AA6092/SiC/25p composite by pulsed-MIG arc welding using unreinforced filler alloys (Al–5Mg and Al–5Si)", *Journal of Materials Processing Technology,* vol. 143-144, pp. 846-850.

Mutombo, K. & Du Toit, M. 2010, "Mechanical Properties of 5083 Aluminium Welds After Manual and Automatic Pulsed Gas Metal Arc Welding Using E5356 Filler", *Materials Science Forum,* vol. 654-656, no. 05/2010, pp. 2560-2560-2563.

ASTM Interanational 2002, "Standard Test Method for Macroetching Metals and Alloys" in , 2002nd edn, ASTM International, West Conshohocken.

ASTM International 2004, *Standard Test Method for Vickers Hardness of Metallic of Materials*, 2004th edn, ASTM international, West Conshohoken.

ASTM International 2004, "Standard Test Methods for Tension Testing of Metallic Materials" in , 2004th edn, ASTM International, West Conshohocken.