Segregation of alloying elements on the hot tear formation in friction melt bonding of Al/steel joints

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Friction melt bonding (FMB) is a promising recent technique to join dissimilar metals with different melting temperatures, in which Al to steel joints are significantly attractive to the automotive industry for weight saving [1, 2]. In an Al/steel lap joint, steel is placed on top and Al beneath. As the tool passes, Al melts and then solidifies as the tool steps away. Occasionally, this process exhibits hot tearing defects in the solidified aluminum zone. A recent study from our research group by Jimenez-Mena et al. (2018), showed a possibility to suppress the hot tear by optimizing the thermal environment of the process [3]. In this study, DP600 steel welded to different aluminum alloys (AA1050, AA6061 and AA7039) were investigated to understand the severity of the hot tear formation due to segregation of alloying elements during solidification. Welds produced with various parameters are characterized to identify the critical elements which favor hot tearing. The base materials of DP600 steel had thicknesses of 0.8 mm while AA1050, AA6061 and AA7039 had the thicknesses of 3.0 mm, 3.0 mm and 17.5 mm respectively. Different material backing plates were used when welding 3mm aluminum plate to DP600 while no backing plate was used when welding AA7039 to DP600 steel. Microstructural characterization Energy dispersive X-ray spectroscopy (EDS) maps were obtained from the transverse section of the weld. A thermomechanical solidification model was also performed using DICTRA® to estimate the amount of segregated elements for an AA6061aluminum alloy.

In the case of AA1050/DP600 welds, the Al reached 650°C (at least the melting temperature of Al), and at that temperature some iron dissolve in the aluminum melt pool and segregate at the grain boundary of the resolidified aluminum region. In the welding case of AA6061/DP600 without hot tear, welded with copper backing plate, it showed large amount of Mg_2Si segregation near the interface. Thermomechanical simulation carried out with DICTRA® for the case of AA6061 solidification under FMB solidification condition predicts that Mg_2Si is formed near the interface of the FMB welds. The hot tear defects are formed for the case of AA6061/DP600 welds performed with brass backing plate, the surrounding regions of the hot tear was severely segregated with Si and Mg. According to DICTRA solidification model, in AA6061, the segregation corresponding to the hot tear zone presents about 5.8% and 6.5% of Mg and Si, respectively. In the third welding case (AA7039/DP600) the aluminum plate thickness was 17.5 mm. Therefore, no backing plate was used. EDS maps obtained at 15 kV accelerating voltage show severe segregation of Zn and Mg near the interface, while some Si was observed near the interface. Quantitative EDS were also performed for longer duration in selected zones, which determine that the segregated zone composition contains large amount of $MgZn_2$ and Mg_3Zn_5 while having small amount of Mg_2Si. Literature shows that Zn combines with large amount of Cu or large Mn, which cause severe segregation [4]. Since the used AA7039 has very low Cu and low Mn fractions, the hot tear susceptibility remains low in our study.

Based on these observations one can clearly see that AA1050 does not have any element to segregate, also never had a hot tear defect in the weld pool. In the case of AA6061, large segregation of Mg and Si occurs near the interface. Depending on the cooling rate during solidification, the segregated zone becomes further vulnerable, and favors the formation of hot tear zone. That is, the cooling rate affects the position of final segregates, Mg and Si, thus with a slow cooling rate (in the case of steel or brass backing plate), this zone forms hot tear defects.

References

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