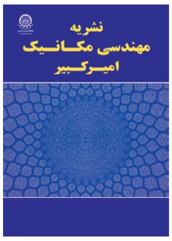

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Numerical Simulation of Laser Welding and Evaluation of Residual Stress and Temperature Distribution in Lap Joint of AA6061 and AA5086 Aluminum Alloys in Different Thicknesses

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ABSTRACT: In the present study, using the ABAQUS 2017 finite element code and using the DFLUX subroutine, a 3D numerical analysis of laser welding in the lap joint of AA6061 and AA5086 aluminum alloys was carried out. The effect of the position of a harder and softer alloy on the upper and lower parts of the weld in two different thicknesses of the two parts was studied on such cases as: thermal distribution, the width of the different welding regions and the residual stress caused by laser welding. In total, and based on the input conditions of the problem, 8 states were prepared for simulation. Based on the results, the A4 sample has the lowest temperature difference between the upper and lower parts in all of these states, which is due to the presence of harder metal with lower thickness in the upper part of the joint. In all cases, regardless of the position of the upper or lower parts, the higher longitudinal residual stresses will occur in the harder part, the AA6061 alloy, and in all states the maximum longitudinal residual stress formed over the yield stress of the harder alloy. Regarding the level of σzz in the workpiece, the best conditions are, respectively, A1 and B1, because they also experience lower residual stresses levels, and the difference in residual stress between the two upper and lower regions of these states is lower.

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1- Introduction

Laser Beam Welding (LBW) as a new method is used in many industries [1, 2]. The lap position LBW is more efficient in production and have better mechanical properties and flexibility in comparison with other configurations like butt and fillet ones [3, 4]. Hence, studying the temperature and heat distribution in lap position LBW is so important. Using numerical methods, one can overcome on time and cost difficulties and present acceptable analysis of the process. Based on the literature review, numerical investigation of lap position LBW in dissimilar metals in various thicknesses has not been performed yet. In this paper, numerical study of lap position LBW of dissimilar Aluminum alloys AA6061 and AA5086 in various thicknesses has been done using ABAQUS.

2- Finite Elements Method

In this study, metal plates with planar dimension of 20 cm×50 cm and 1 mm and 1.5 mm in thickness have been used for finite elements modeling. Also, the arrangement of top-bottom placement of metals has been deliberated. Due to symmetry, one half of work pieces have been used for modeling. Welding and cooling processes analysis is performed in the first and second thermal steps with 5 s and 30 s durations, respectively. In the third step, the thermal results obtained from previous steps are used to calculate the residual stresses in workpieces. Every workpiece in this analysis has two thicknesses and two positions which results in eight separated analysis which are illustrated in Table 1.

Due to existence of strain rate in process, the Johnson-Cook viscoplastic relation [5] is used which the coefficients of mentioned relation are obtained from previous researches [6, 7]. Other mechanical and thermal properties are also obtained [8].

3- Heat Source Modeling

In LBW simulation, it is usual to use Gaussian heat distribution, which the exerted heat is changed across the radius. In current study the popular C-I-N model has been used.

$$q_v(r,z)=\frac{kK_yQ_L}{\pi\left(1-e^{(K_ys)}\right)}e^{-(kr^2+K_yy)}\left[1-u(y-s)\right] \quad (1)$$

The depth of laser beam penetration, laser beam power,

Table 1. Considered simulation states

Sample	Top Plate	Bottom Plate	Top Plate Thickness	Bottom Plate Thickness
A1	Al6061	Al5086	1.5	1.5
A2	Al6061	Al5086	1.5	1
A3	Al6061	Al5086	1	1
A4	Al6061	Al5086	1	1.5
B1	Al5086	Al6061	1.5	1.5
B2	Al5086	Al6061	1.5	1
B3	Al5086	Al6061	1	1
B4	Al5086	Al6061	1	1.5

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laser beam radius and laser beam progress speed have been considered as 3 mm, 600 W, 1 mm and 1 cm/s, respectively. To exert moving heat flux, a DFLUX subroutine code written in FORTRAN, has been used.

4- Results and Discussion

Based on obtained results, the maximum temperature was observed in sample *B*3. In Figs. 1 and 2, the temperature change across the thickness have been plotted for *A* and *B* categories, respectively.

Due to the results shown in Figs. 1 and 2, in all situations, by increasing the thickness, the maximum temperature in each workpiece decreases which the reason of this is that the more amount of material is faced against the laser beam source which results in heat distribution in bigger area and noticeable decrement in maximum obtained temperature. Based on the results, it was obtained that the maximum temperature change process doesn't depend of work pieces placement.

In current study, the longitudinal and transverse residual stresses across the thickness have been investigated. The longitudinal residual stresses across the thickness in categories *A* and *B* have been shown in Figs. 3 and 4, respectively.

Based on Figs. 3 and 4, the maximum longitudinal residual stresses takes place at the harder alloy AA6061, in all situations, which is due to higher thermal stress concentration in this workpiece. In all situations, a disconnection is seen in the intersection of workpieces and residual stress is changed abruptly in this region which is due to asymmetric heat distribution.

The transverse residual stresses across the thickness in categories A and B have been shown in Figs. 5 and 6, respectively.

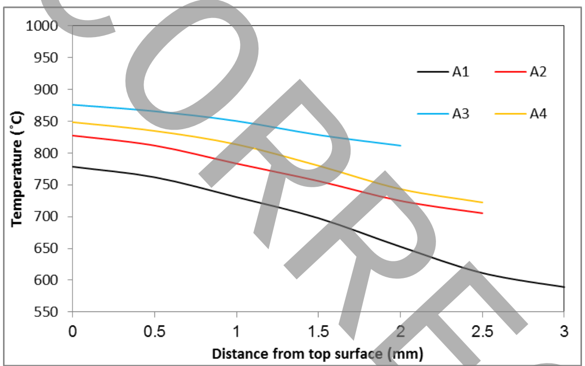

Fig. 1. Temperature change across the thickness for Sample *A*

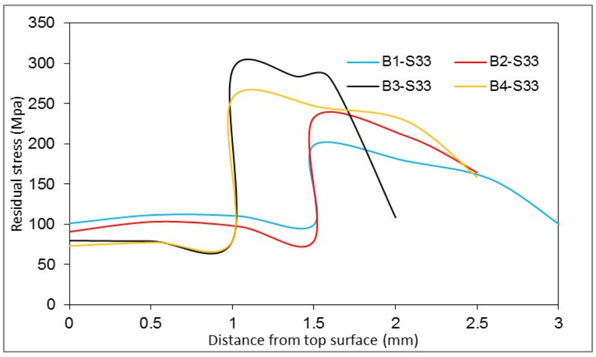

Fig. 4. The longitudinal residual stresses across the thickness

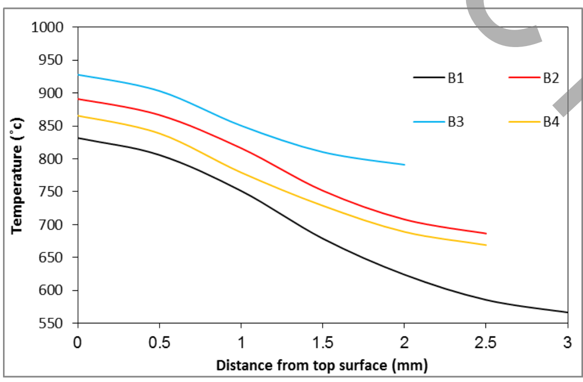

Fig. 2. Temperature change across the thickness for Sample *B*

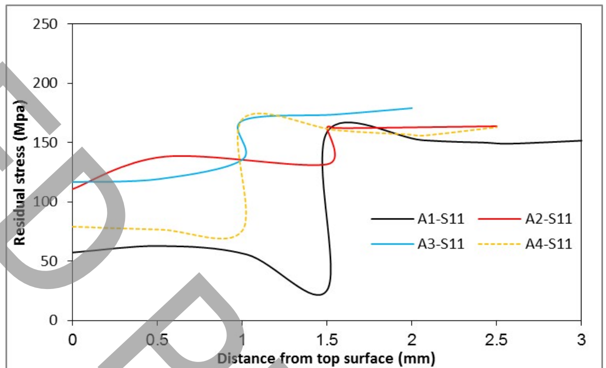

Fig. 5. The transverse residual stress (σ_{xx}) in *A* samples

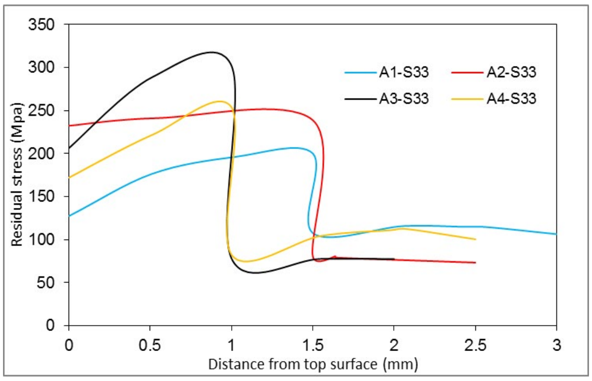

Fig. 3. The longitudinal residual stresses across the thickness

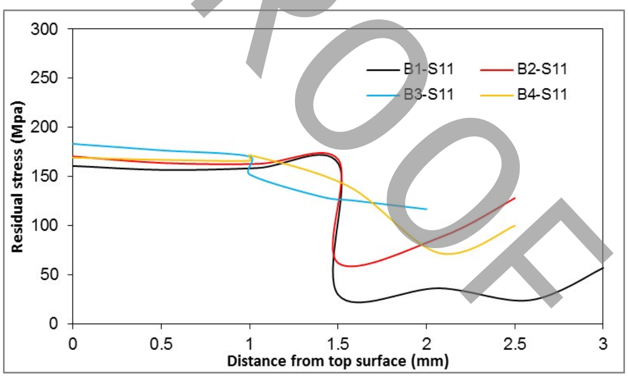

Fig. 6. The transverse residual stress (σ_{xx}) in *B* samples

Based on Figs. 5 and 6, the transverse residual stress (σ_{xx}) in all situations take places at more ductile alloy (AA5086) which is against the result obtained from the longitudinal residual stress analysis. Another important result is that the transverse residual stresses are almost 30% lower than longitudinal residual stresses.

5- Conclusion

In every workpieces in category B, which the more ductile alloy is above, the higher maximum temperature is obtained in comparison with corresponding workpieces in category *A*, which is due to lower specific heat in category *B*.

In the case of equality of sum of the thicknesses of the workpieces, if the thickness of top plate is higher than the low one, the relatively higher temperature distribution take places in the whole workpiece which is due to the effect of distance between the intersection and the heat source.

In all workpieces, the maximum transverse residual stresses take place in more ductile alloy and are lower in comparison with maximum longitudinal residual stresses.

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