Welding Distortion Analysis of Magnesium Tubular Connections

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Introduction

Driven by the need to minimize vehicle weight and use more environmentally friendly materials, automakers are showing increased interest in incorporating magnesium into the production of next generation vehicles. Magnesium's unique lightweight and high-strength characteristics make its use a viable option. To achieve maximum weight savings, large vehicle body structures, those currently fabricated of steel or aluminum could be manufactured from magnesium alloys. One of the process issues critical to welding thin-wall, tubular structures is residual stresses and distortion. This paper studies the thermal-mechanical characteristics of a typical thin-wall tubular connection made of AZ91D magnesium alloy using the finite element analysis (FEA) procedure. The results are compared with the same tubular connection made of steel and aluminum.

Procedure

A tubular Tee-connection consisting of square-butt and tee joints was analyzed. The mockup model was fully clamped at one end of the flange tube with transverse displacements constrained at a cross-section in the other end of the flange tube and at the end of the tee stem. The connection was tacked at four corners in the tee-joints. Gas metal arc welding (GMAW) process was used to make two butt and two tee welds. Transverse constraints were released after the connection completely cools off to room temperature.

The parameters studied were (1) material properties, (2) welding sequence, (3) constraint conditions, (4) welding heat pulsation, and (5) supplementary heating. The FEA procedure was calibrated using the moving-source model, which also determined the plasticity zones and distributions in the joints. A plasticity-based engineering methodology was developed for the parametric studies. AISI 1030 steel, 5456H116 aluminum and AZ91D magnesium alloys were used in the study.

Results and Discussion

Two kinds of significant results were obtained from this study. The first kind is the verification of the plasticity-based theory that welding distortion can be uniquely determined by the equivalent plastic strains in the weld joints These equivalent strains, primarily existing in the softening zones bounded by the material softening temperature, are significant in determining welding distortion. This means that only nonlinear heat flow analysis is required to determine the softening boundaries. Distortion can then be determined by incorporating a negative temperature rang in the softening zones to establish the equivalent plasticity in the joints. The mechanical analysis requires only linear-elastic procedure.

The other kind of results is derived from the parametric studies. For the same equivalent cross-sectional stiffness, steel connection is more dimensionally stable during welding than that made of aluminum or magnesium alloys due to steel's higher softening temperature and smaller thermal expansion coefficient. Aluminum and magnesium alloys have similar thermal and mechanical properties and welding characteristics, but magnesium is more sensitive to the process and jigging variations.

The specific heat of magnesium is about the same as aluminum, but if considered on a volume basis it is about three quarters that of aluminum. Since the melting temperature of magnesium and aluminum are nearly the same and the latent heat of fusion of magnesium is somewhat lower than that of aluminum, the heat required to melt magnesium is only two thirds that for the same volume of aluminum. In addition, the thermal diffusivity of magnesium is about half that of aluminum, but three and half times that of steel. With the low heat input requirement of magnesium, it is critical to contain the heat within the weld to ensure adequate fusion and penetration while keeping the thermal gradient small by supplementary heating. This would mean either preheating the workpieces, using heat pulsation, or applying localized supplementary heat to the surroundings of the arc area.

Due to high coefficient of thermal expansion magnesium has a tendency towards distortion, especially when welding thinner components buckling is more likely to occur. Using strong and distributed jigging is effective to contain both the dynamic changes of joint details during welding and the global structural distortion after welding. Utilizing a welding sequence following joint rigidity (e.g. butt joint first then tee joints), arc pulsation, or two diffused supplementary heat sources moving together with the welding arc is also effective in containing the distortion.

Conclusions

1. This study demonstrated the unique relationship between the plasticity and welding distortion. This plasticity-based prediction procedure is effective in estimating welding distortion with good accuracy.
2. Magnesium is more prone to welding distortion than steel or aluminum due to primarily its low softening temperature and higher expansion coefficient. Heat must be contained within the fusion zones and thermal gradient in the base metal must also be contained in order to prevent thin-wall tube from buckling.

3. The heat control algorithm including arc pulsation and use of supplementary heat source is effective in controlling welding distortion in thin-wall tubular connections made of AZ91D magnesium alloy.