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Weldability of CuZn30 Brass/DP600 Steel Couple by Friction Stir Spot Welding

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This study deals with the weldability and assessment of the friction stir spot welding of dissimilar CuZn30 brass/DP600 steel couple. The effects of axial tool load and tool hold time were evaluated in the joining experiments. The tool load forces of 3.2 − 4.8 kN and the tool hold times of 8 s and 12 s were applied to brass/steel bimetal sheets. Tensile-shear test was employed to investigate the mechanical properties of the joint. Optical and scanning electron microscopies were utilized to characterize the microstructure of the joint having the better mechanical performance, as well as the microhardness test. Temperature measurements were also performed between the lapped sheet faces. The results show that the vertical tool load value has reached more significant influence than the tool hold time. Furthermore, the tensile-shear failure load has increased with increasing tool load and hold time and has reached the highest value of 4.6 kN. The EDS analyses on the fractured surface depict that the copper and zinc concentrations are similar to those of CuZn30 base metal. A peak temperature of 607 °C was measured in the weld centre of this joint. No significant microstructural change was observed in the steel sheet, while the fine grains with onion rings were revealed in the brass. Different hardness values were measured depending on microstructural change in the weld zone. Although the onion rings made a contribution to the microhardness, a softened stir zone (129.8 HV), with regard to the brass base metal (149.1 HV), was observed.

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1. Introduction

Dual phase (DP) steels are suitable for automotive applications, since they have high strength-to-weight ratios and work-hardening rate, improved formability and good corrosion resistance [1, 2]. Brass sheets have also been used in heat exchangers, radiator, and charge air cooler for diesel engine, due to combination of their high thermal conductivity and a higher strength at elevated operating temperatures [3]. Resistance spot welding technique is widely applied to joining of similar metals, especially for steel sheets in automotive industry [4, 5]. Nowadays, welding of dissimilar metal couples became more attractive, since metal couples have a potential to fulfill the requirements under same service conditions. Therefore studies concerning welding method and materials have been carried out [6, 7]. Although the joining of steel to another metal by friction stir spot welding (FSSW) has been studied [2, 3, 8, 9], a study of steel to brass welding could not be found in the literature survey. Thus, the present study aimed to show the weldability of CuZn30/DP600 bimetal couple and to evaluate the weld performances under the various axial loads and hold times of the tool.

2. Materials and methods

Brass sheet (30.5 wt.% Zn, balance Cu) at top and galvanized DP600 steel sheet (0.107 wt.% C, 1.599 wt.% Mn, 0.324 wt.% Si, 0.096 wt.% Cr, 0.038 wt.% Al, 0.014 wt.% Ti, balance Fe) at bottom, with dimensions of 100 mm × 25 mm × 1 mm were friction stir spot welded (FSSWed). The FSSW trials were made using a tool consisting of a concave shoulder (∅ 15 mm) and a pin with length of 0.6 mm. The axial tool load during the trials was simultaneously recorded via a data acquisition system, connected with two load-cells, placed at the bottom of the backing plate. Axial tool loads of 3.2, 3.6, 4.0, 4.4 and 4.8 kN were employed, as well as two tool holding times of 8 s and 12 s, under a constant tool rotation speed of 1200 rpm. The tool was kept perpendicular to surface of sheets in all trials. A K-type thermocouple (∅ 1 mm) was used to determine the top temperature at the interface of overlapping dissimilar sheets.

The tensile-shear tests were done in order to determine the mechanical properties of weld trials by a Shimadzu test machine, with the crosshead speed of 2.5 mm min^{-1}. After this point, the following examinations were realized on the FSSWed joint having a maximal tensile-shear failure load (TSFL). Brass was etched by a solution consisting of 100 ml of H_2O, 4 ml of saturated NaCl, 2 g of $Cr_2K_2O_7$, and 5 ml of H_2SO_4 and 2% Nital was used to etch DP600 steel, following the standard metallographic cross-sectional specimen preparing procedure for this weld. A Nikon Eclipse L150A optical microscope was utilized to microstructural examination. A JEOL JSM 6060LV scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDS) apparatus was used to characterize the fracture surface. Vickers microhardness testing was employed on the metallographic examination specimen by using a load of 100 g for dwell time of 10 s.

3. Results and discussion

It can be firstly said that defect-free weld trials could be achieved under all FSSW conditions used, according to the visual inspection. The shinning keyholes were produced by the tool shoulder and pin peripheries. In addition color changessurrounding the keyholes, due to heat input, have clearly been observed.

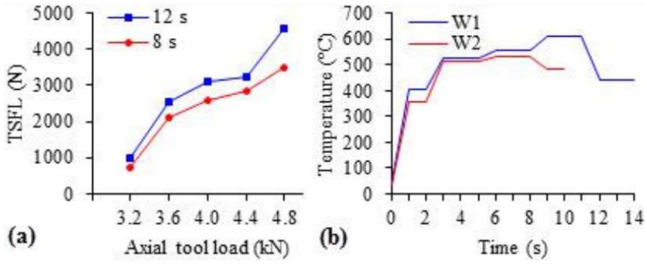

Fig. 1. (a) TSFL values of all FSSW trials, (b) temperatures in the weld centre of W1 and W2.

Figure 1a shows TSFL values related to FSSW conditions. TSFL increased with increasing of the axial load and holding time of the tool. It reached about 4.6 kN under the conditions of the axial load of 4.8 kN and hold time of 12 s (hereafter, called as W1). However, a higher TSFL was obtained at the low hold time (8 s) at the highest axial tool load (hereafter, called as W2), compared to the other weld trials, except W1. The button pull out type fracture had occurred on the samples, for axial tool loads of 4.0, 4.4 and 4.8 kN (Fig. 2a). In case of lower axial tool load then 4.0 kN, the samples failed across the interface of the sheets, as shown in Fig. 2b. In addition, all joint trials at hold time of 8 s, except W2, depicted the interfacial fracture mode, which is an unfavorable event, owing to low ability of the interface to absorb energy.

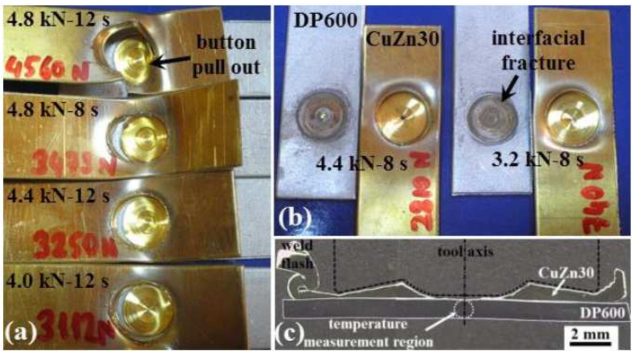

Fig. 2. Failed samples with different failing modes: (a) button pull out type, (b) interfacial type (c) macro-image of W1.

Therefore, it can be said that the axial tool load plays a significant role in a sound weld achievement in dissimilar CuZn30/DP600 couple. The fracture in W1 initiates from the upper brass sheet under the shoulder edge, which is the thinnest section and propagates through the brass, where it is in contact with the circumference of the shoulder. This indicates that the sufficient metallurgical bonding had formed in area between the shoulder outer edge and the pin. It is believed that the weld zone should be exposed during the process to a peak temperature higher than a certain value, because it is well known that increasing of axial tool load and/or tool hold time results in the increase of the heat input.

Regarding the results of temperature measurement under the pin centre for W1 and W2, which displayed button pull out fracture, the peak temperature mentioned above should be higher than 500 °C. It was recorded around 600 °C for the best weld, W1 (Fig. 1b). Although this peak temperature is enough for recrystallization of the brass, it is lower than the melting and the zinc evaporation points. On the other hand, a martensitic transformation did not occur in DP600 steel, since this temperature is below the austenization temperature.

The macrograph without cavity void of W1 is seen in Fig. 2c. It is clearly seen that the tool has decreased the thickness of the upper CuZn30 sheet. The brass has almost the same appearance, as the tool section. It is noticed that the brass sheet section was more thinned at the side where excessive weld flash had occurred. However, a considerable deformation, penetration and/or wave-like mixing of metals have not been observed in the lower DP600 steel sheet, since the pin did not plunge into it.

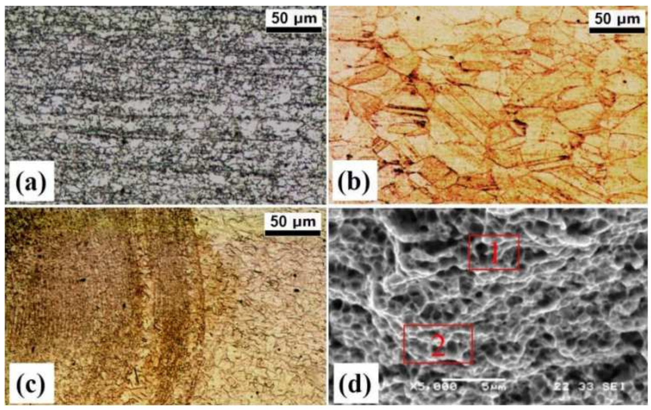

Fig. 3. Microstructures in W1 (a) DP600 BM, (b) CuZn30 BM, (c) SZ and (d) SEM image on fractured surface.

Therefore, typical microstructural changes in frictional weld processes were not obviously observed in this material. Namely, microstructure consisting of ferrite matrix and martensite, similar to the base metal (BM) was seen the weld zone, as is shown in Fig. 3a.

As for the upper brass sheet, which had contacted with the tool, it has undergone a microstructural evolution due to the elevated temperature in combination with plastic deformation. Heat affected zone (HAZ) with coarse grains and thermo-mechanically affected zone, characterized by elongated grains, were not detected, as reported in previous studies [10, 11]. This may be attributed to fact, that relatively low heat input and/or its duration time, did not allow the grain growth for HAZ formation.

On the other hand, a stir zone (SZ), including recrystallized finer grains was determined, compared with CuZn30 BM, which contains large deformation twins (Fig. 3b).

The onion rings consisting of finer grains were also observed (Fig. 3c). Xie et al. [12] have assumed that onion rings tend to appear under conditions of lower stirring and heat input. This inference is partially in agreement with the present study, because the onion rings have formed in regions close to the pin outer surface, due to severe stirring action.

The microhardnesses of DP600 BM and CuZn30 BM are 228.6 $HV_{0.1}$ and 149.1 $HV_{0.1}$, respectively. A softening has been clearly detected in SZ at the upper brass, in spite of the smaller grains. The mean hardness here has dropped to 129.8 $HV_{0.1}$. This shows that the hardness can not be correlated with grain size, according to Hall-Petch relation. However, the onion rings region has a mean hardness of 165.8 $HV_{0.1}$; hence the onion rings have contributed to increasing of the hardness and TSFL.

Figure 3d shows SEM image of the brass side, where crack initiation has occurred during the tensile-shear test. The dimples imply the ductile fracture, however the tensile dimples are obvious taking into account the elongated shear dimples. This can be attributed to fact that the plastic deformation mainly occurred in CuZn30 rather than in DP600 steel.

EDS analyses, taken from the areas marked by 1 and 2 in Fig. 3d, have resulted in 68.574 wt.% Cu, 31.426 wt.% Zn and 67.360 wt.% Cu, 32.640 wt.% Zn, respectively. Such concentrations in this section can be considered akin to the brass base metal.

4. Conclusions

In this study, CuZn30/DP600 bimetal sheets were FSSWed under the axial tool loads of 3.2–4.8 kN at two tool hold times of 8 s and 12 s. The key conclusions resulting from the study are: (i) TSFL increased with the increasing of the tool load and hold time; (ii) the tool load has a major influence on the achievement of good joint quality and metallurgical bonding. The best weld performance is 4.6 kN at the load of 4.8 kN and hold time of 12 s. The peak temperature of 607 °C was measured under the pin tip for the best weld. The weld zone of this joint was mainly formed in SZ, consisting of recrystallized finer brass grains as well as BMs. Although a softened SZ was produced, in comparison with the brass BM, the hardness of onion rings in SZ is higher than that of CuZn30 BM. The ductile fracture occurred at the brass sheet and a remarkable change in the concentration of this failed section were not detected in the SEM photograph and EDS analysis.

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