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Heterogeneous mechanical behavior of dissimilar aluminum alloys FSWed joints assessed by OHR-DIC characterizations

R. BERTRAND^{a,b,c}, D. TEXIER^{a,b}, H. ROBE^{c,d}, Y. ZEDAN^{a,b}, E. FEULVARCH^{b,c},
P. BOCHER^{a,b}

a. Mechanical Engineering Department, École de technologie supérieure (ÉTS), 1100 Rue Notre-Dame Ouest, Montréal H3C 1K3, Québec (Canada)

b. REGAL-Laval, 1065 avenue de la Médecine, Québec G1V 0A6, Québec (Canada)

c. Univ Lyon, ENISE, LTDS UMR 5513 CNRS, 58 rue Jean Parot, 42023, Saint-Etienne cedex 02 (France)

d. TRA-C industrie, ZAC des Olmes, Allée du Savoir-faire, 69490 Les Olmes (France)

Abstract:

Friction stir welding of dissimilar heat treatable 2139-T8 and 7020-T651 aluminum alloys was investigated in a large operating window of industrial welding parameters. Detailed microstructural and local mechanical characterizations have shown that despite consistency in the macroscopic tensile behavior of the different processed joints, local discrepancies in hardness highlighted the sensitivity of the two aluminum alloys to the welding process parameters. For this reason, a local characterization of the joint was undertaken. The local tensile behavior of the joints was investigated at the microstructure scale thanks to the use of an optical high-resolution digital image correlation (OHR-DIC) technique. The aim of this in-situ microtensile technique was to accurately calculate the local strain fields in the cross-weld section from kinematic field measurements. OHR-DIC micro-mechanical analysis demonstrated that strain localization first appears in the nugget region, then in the HAZ leading to fracture in this latter region. This study gives the opportunity to get an overall view of the welding parameters influence on the microstructural and mechanical characteristics of the welded joints and thus, make the right industrial choice according to the application.

Keywords: FSWed dissimilar aluminum joint, Hybrid lightweight design, Digital image correlation, Tensile behavior

Introduction

Currently, reducing the weight of transport structure is an important challenge. The aluminum alloys (AA) 7020 comply with this constraint. AA7020 is a medium strength Al-Zn-Mg alloy well known for its good mechanical performance [1]. However, Al-Cu-Mg alloys, such as AA2139, will progressively replace 7XXX alloys because of the conjunction of higher mechanical strength and lower density [2]. Unfortunately, the intensive use of AA2139 is limited due to the production cost. Building hybrid structure by assembling medium-performance and high-performance aluminum alloys as a function of the local stresses in the structure is an attractive solution for cost-effective design strategies. In order to assemble these dissimilar alloys, Friction Stir Welding (FSW) is particularly suitable. Several process parameters, such as speeds [3], axial force [4], plates position [5], were reported to influence both the material flow of the weld and the mechanical behavior. In the present study, various dissimilar joints AA2139-T8/AA7020-T651 were produced with a large range of industrial welding parameters in order to correlate these parameters with the local mechanical behavior.

Materials and procedures

Two 5 mm-thick sheets made of AA2139-T8 on the advancing side (AS) and AA7020-T651 on the retreating side (RS) were friction stir welded with a TriflatTM tool. The rolling direction of

the sheets was always perpendicular of the welding direction. Five process parameters were used, with a fixed tilt angle of 1.5° , a rotation speed ranging from 600 to $1000 \text{ rev.min}^{-1}$ and an advance speed ranging from 250 to 550 mm.min^{-1} . Welds were studied after a 5 months natural aging time. FSWed samples were extracted and prepared in order to perform cross-section macrographs and Vickers microhardness maps. Macro- and microtensile tests were carried out. For each condition, local strain fields of the deformed joint were assessed by OHR-DIC [6] in the cross-welding direction/normal direction plane for various loadings.

Results and discussion

Defect-free joints were produced with a rather similar macrostructure in this range of welding parameters. For all welding conditions, macrographs revealed typical features of FSWed joints in terms of grain size evolution in the various areas (nugget, TMAZ, HAZ and base materials). An example is given Fig. 1a.

Hardness maps (Fig. 1b) showed that nugget have globally a lower hardness than both base material. The two materials in the nugget exhibited very comparable hardness values, making them hard to distinguish. It worth mentioning that the minimum hardness region (MHR) was systematically found on the AA7020 side (RS) at a distance between 7 and 13 mm far from the center line (HAZ). This distance decrease when the rotation speed increase. The MHR is due to a thermal effect leading to precipitate coarsening.

The macroscopic tensile performances of the whole joints were similar in this range of welding parameters. Joint necking and fracture always occurred on the MHR. However, a step-by-step local plastic strain measurements campaign (Fig. 1c) revealed that strain localization first occurred in the nugget at 283 MPa. Strain localization happens at the MHR for a stress level about 20 MPa higher.

While the hardness map and the fracture surface features have suggested coarse precipitates and high ductile material in the MHR, the early plasticity in the nugget region was not expected from microhardness measurements. This early strain localization could play an important feature in fatigue. Differences in strain hardening of the nugget and the MHR together with some stress triaxiality related to the thickness of the related soft regions lead to intense strain localization in the MHR at high deformations.

Conclusions

OHR-DIC allowed to highlight the heterogeneous behavior of the joint for several stages of the tensile test. In particular, it has shown that the area where the deformation begins, i.e. the nugget, is not the fracture area, i.e. the MHR. This is explained by the disparities of locale tensile behavior of these areas.

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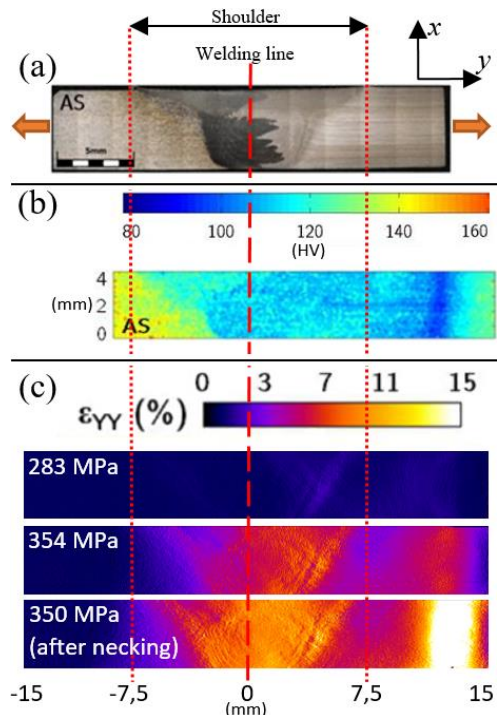


Figure 1: (a) microstructure, (b) microhardness and (c) local plastics strain in loading direction for various stresses in cross-section (250 mm.min^{-1} , 600 rev.min^{-1})