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Experimental investigation of mechanical properties, formability and forming limit diagrams for tailor-welded blanks produced by friction stir welding

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ABSTRACT

In this study, the mechanical properties, formability and forming limit diagrams (FLDs) of the tailor-welded blanks (TWBs) produced by friction stir welding (FSW) were analyzed experimentally. At first, the suitable FSW parameters were achieved. The formability and FLDs of TWBs were evaluated for sheets with the same or different thicknesses and compared to the base metal sheet. This study was performed on low carbon steel (St14) sheets with a lot of applications in automobile industries. The welded zone properties were evaluated by some experiments. The tensile test, micro hardness testing, and metallographic studies were done. The effect of welding seam directions on formability and FLD were investigated concerning two aspects. The welding process was carried out in rolling and transverse directions with no effect on formability, and then the welding process was performed in the principal stress direction and perpendicular to it; these directions had a significant effect on formability. Also, it was revealed that welding caused formability decrease, and in TWBs with different thicknesses, this negative effect was higher. In addition, the initial orientation of sheets had none effect on FSW process.

1. Introduction

Tailor welded blanks are metallic sheets made of different strengths, materials, and/or thicknesses pre-welded together before forming into the final component geometry. By combining various sheets into a welded blank, engineers are able to ‘tailor’ the blank so that the properties are located precisely where they are needed and cost-effective, hence, low weight components can be produced [1–4].

Forming limit diagram (FLD) has been known as an effective tool for the formability investigation of sheet metals and TWBs. Forming limit curve (FLC) is often used to predict the forming behavior of sheet metals [5,6]. FLDs could be achieved both theoretically and experimentally [7,8]. To find FLD, the sheet metal is subjected to various stress combinations leading to various sets of principal stresses and principal strains. For this purpose, some sheet metal specimens of constant lengths and variable widths are stretched by a hemispherical punch (out of plane stretching) or flat punch (in-plane stretching), and some constant geometry specimens are stretched using different lubricants [9,10].

In recent years, some researchers have attempted to investigate properties and formability of TWBs by different methods. Rojek et al. [11] determined the mechanical properties of the weld zone in tailor-welded blanks. They presented different methods to determine mechanical properties of the weld zone in tailor-welded blanks. They used methods including metallographic observations, uniaxial tension tests, micro-hardness tests, and indentation tests combined with inverse numerical analysis. They obtained and compared stress–strain relationships for the weld zone in a steel laser welded blank using different methods. Riyahi and Amini [12] studied the effect of location change of weld zone and differences in thickness combination of TWB sheets on their tensile characteristics and forming capabilities. They consumed laser welding TWB made of St14 sheets. By conducting metallurgical and mechanical microstructure, tensile characteristics and formability of TWB were analyzed. They concluded that weld area does not play a major role in tensile forming of TWB, and by dislocating weld line towards the thick sheet, formability of TWB samples increases, also by reduction in thickness difference of sheets forming TWB, their formability increases. Bayraktar et al. [13] compared the mechanical and metallurgical aspects of tailored welded blanks. They made a comparative study for microstructural and mechanical-toughness characterization of the steel assemblies, base metal or welded by LASER. These studies can facilitate the estimation of the influence

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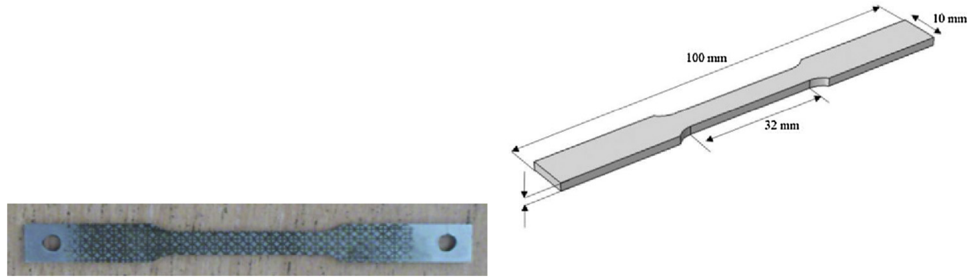

Fig. 1. Dimensions of the sub-size specimens used in tensile tests.

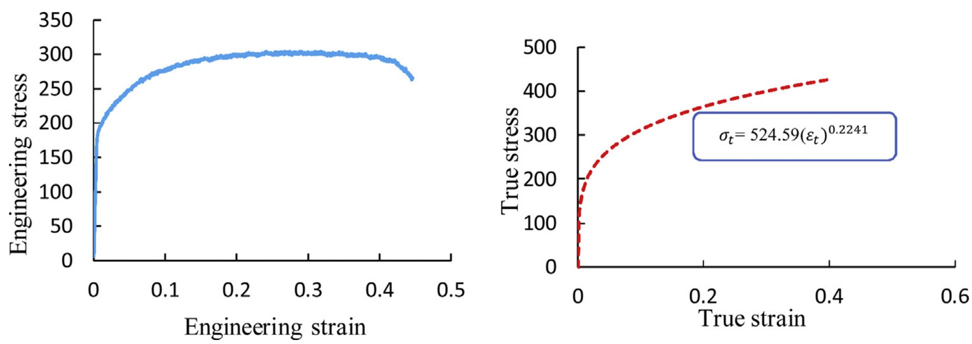

Fig. 2. Strain-stress diagram for steel St14.

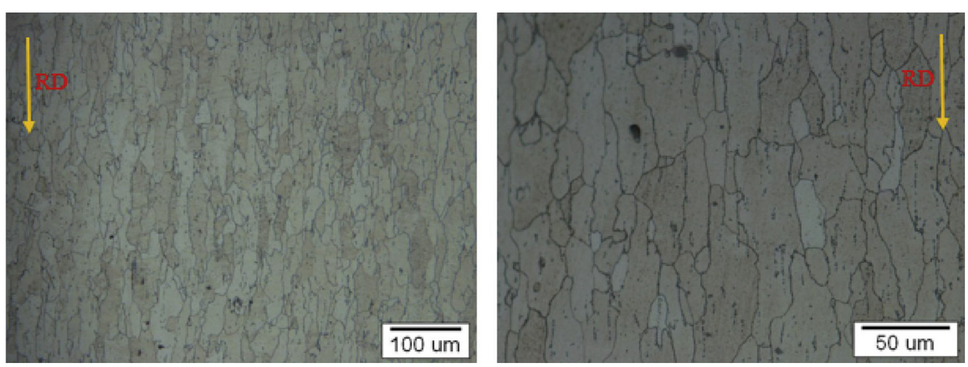

Fig. 3. Micro-structure of St14 base sheet.

of the welding conditions and/or the influence of the chemical compositions on the toughness behaviors of the welded joints by LASER process. They demonstrated that the new type of temperature transition diagrams provides many possibilities to explain purely damage mechanism of each part of the pieces, BM, HAZ, and weld bead in case of failure in the specimens because the geometry of the specimen does never give a fracture deviation from the welded part (harder zone) to the base metal (softer zone), as usually observed in the classical dynamic crash tests. Padmanabhan et al. [14] employed finite element simulations to determine the formability characteristics of aluminum–steel TWBs. They illustrated that even with large dissimilarities in material properties, Al–steel TWBs can produce superior deep drawn parts. In all combinations of Al– steel TWBs, weaker aluminum is subjected to greater plastic deformation, and hence the welded line shifts towards steel side. Tusek et al. [15] studied the welding of tailored blanks of different materials. They checked some kind of welding with or without fusion and with or without filler material, and then studied welding joints after deep drawing. They concluded that the most suitable process for welding tailored blanks of different materials is welding without melting and welding tailored blanks of stainless high alloy and non-stainless ferrite steel carried out by melting with a filler material. Chan et al. [16] investigated formability and weld zone analysis of tailor-welded blanks with various thickness ratios. They used Nd:YAG laser butt welding to weld the TWB specimens of different thickness ratios. The findings demonstrated that higher thickness ratio of TWBs results in lower formability. Also, the results of uniaxial tensile tests clearly showed no significant difference between the tensile strengths of TWBs and those of base metals. The metallographic study illustrated grain size difference in the materials at base metal, heat-affected zones, and fusion zone. The micro-hardness measurement showed that the hardness in the fusion zone increased by about 60% of the base metal. Mamusi et al. [17] achieved a novel numerical method to determine forming limit diagrams for TWBs. They presented the results of simulated hemispherical die stretching of laser-welded, low carbon steel (ST12 and ST14) blanks of various thicknesses. Their proposed method was fairly accurate and computationally inexpensive. It could be easily carried out for FLD, creating in a laboratory setting with little need to user input and subjectivity.

In this paper, TWBs produced with Friction Stir Welding (FSW) were studied. First, the optimized parameters for FSW process were achieved through metallographic studies, tensile test, and visual inspections. Welding was performed at rolling direction and