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Experimental investigation on high strength steel (HSS) tailor-welded blanks (TWBs)

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ABSTRACT

This paper aims to investigate mechanical characteristics of the new tailor-welded blank (TWB) components made of high strength steel (HSS). A series of HSS-TWB thin plates with different orientations of weld line are studied through three-point bending tests to evaluate the effects of different design parameters, such as weld line locations and material combinations, on the deformation behaviors. The experimental results exhibit good repeatability of tests. And the relative shift phenomenon between indenter and specimen is observed and analyzed for the TWB steel sheets with different weld line orientations at parallel and 45° to the bending moment, respectively. The results from the experiment include the force versus displacement curves and some detailed photographical images throughout the loading process. It is found that the discrepancy of different combinations is quite noteworthy. In this paper, the peak force, absorbed energy and bending strength are presented to evaluate the mechanical characteristics of HSS-TWB thin plates with different weld line orientations and material combinations. The comparison demonstrates that the TWB structures with the weld orientation at 45° angle to the bending moment have the greatest advantages of different TWB steel sheets.

1. Introduction

To meet an increasing demand in reducing vehicular weight, high-strength sheet (HSS) metals are more and more extensively utilized in the field of transportation industry. Automotive engineering has recently developed a strong interest in tailor-welded blanks (TWBs) technology. For example, Jie et al. (2007) studied on formality of TWBs made of aluminum sheets using both experimental and numerical approaches. Abbasi et al. (2012) summarized wall wrinkling tendency of a TWB consisted of interstitial free (IF) steels with different thicknesses. As a matter of fact, TWBs make it possible to use different materials to form a single component which enables the designer to better tailor the usage of materials and thickness for specific purposes. This technology provides tremendous flexibility in the design course of new stamped structures. A TWB component is fabricated of two or more high-strength metal sheets with different materials and/or different thicknesses welded together into a single component prior to forming process. Not only does this process save materials and reduce cost in stamping and assembling, but also improve crashworthiness by purposely enhancing the stiffness, strength and the capacity of energy absorption.

Main difference between the TWBs and uniform blanks lies in the existence of weld seam. Bayraktar et al. (2005) indicated that laser-welded TWBs have weld beads whose strength and hardness are significantly higher while the ductility is generally lower than the surrounding base materials. Such discrepancy could lead to two major modes of failures observed in the forming process of TWBs. The first mode corresponds to the perpendicular direction of the bending moment, i.e. longitudinal loading, in which the failure occurs across the weld line. The second mode corresponds to the parallel direction of the bending moment, i.e. transverse loading, and the failure mode is likely related to the material properties inside the weaker base material. As observed, these two failure modes largely depend on the orientation of the weld line relative to the principal stretch axis. For each typical welding location and orientation, Gaied et al. (2009) described several different configurations: e.g. (1) the same thickness with different material grades; (2) different thicknesses with the same material grade; and (3) different thicknesses with different material grades. The forming behavior and failure mode of an intrinsic TWB rely on its own structural configurations of thickness and/or material combination as well as the weld line location and orientation.

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Many recent studies on the TWBs structures have focused on the formability and their applications. For instance, Padmanabhan et al. (2007) evaluated on the forming characteristics of TWB sheet metals via different deep drawing tests. Panda and Ravi Kumar (2010) proposed the formability of three different types of TWBs in biaxial stretch forming modes by conducting limiting dome height (LDH) tests. Although these standard physical tests could, to a certain extent, quantify the formability of TWB structures experimentally and measure the weld line movement, they had limitations to revealing some critical details in forming mechanics and TWB design. On the other hand, the existing formability studies on the welded blank sheets mainly concerned on the combined effects of the mechanical forming performance with different base materials, weld zones and the orientations of weld lines.

In addition to conventional tension and stamping characteristics, some advanced engineering materials are of high bending stiffness and strength. In this case, the three-point bending test appears to be effective and often provides fairly specific insights into deformation characteristics. For example, Chung et al. (2009) performed both the uni-axial tensile and three-point bending tests. Nevertheless, the tests were only used to verify the characterization method developed for the weld zones. Three-point bending tests were also applied to characterize mechanical behaviors in different materials. For example, Zhao and Lee (2002) reported the cyclic three-point bending tests of both mild steel and high strength steel, in which the strain hardening and Bauschinger effects of both materials were also detected. Omerspahic et al. (2006) determined the plastic hardening parameters of different materials by comparing the load and displacement curves from experimental and FE simulations of three-point cyclic bending tests. Rathnaweera et al. (2012) conducted the quasi-static and dynamic three-point bending tests to determine the load carrying capacity of an advanced high strength steel (AHSS) and extruded cylindrical tubes made of aluminum alloys.

Despite more and more extensive use of TWB technology, investigations into the bending behaviors of HSS-TWB thin plates have still been under studied in literature. There is increasing urgency for thoroughly characterizing mechanical bending behaviors of different TWB structures. It is therefore of considerable importance to better understand the three-point bending characteristics of TWB thin plates by taking into account the effects of weld line locations and different material and/or thickness combinations. In this paper, a set of TWBs high-strength steel (HSS) thin plates with different weld line orientations and material combinations are used to conduct the three-point bending tests for evaluating the effects of different TWB parameters on the mechanical behaviors. The TWB sheets with three different weld line orientations of parallel, perpendicular and 45° angle to the bending moment are utilized to measure their mechanical behaviors, respectively. From the force versus displacement curves, peak force, energy absorption, bending strength and photographical images, it is found that the discrepancy of different combinations is quite noteworthy for a given weld orientation. The comparison demonstrates that the TWBs with the 45° weld orientation to the bending moment have the greatest advantages of TWBs steel sheets.

2. Materials and methods

In order to determine the deformation behaviors, a series of three point bending tests are conducted for the TWB high-strength steel (HSS) plates with the different weld orientations. There are three steps for the three-point bending test procedure of the TWB specimens conducted in this study. The first step involves the preparations of the base steel sheets by using a plate shearing machine. The second step is to weld the sheets using laser welding technology, which ensures the width of weld lines to be sufficiently narrow with the desired quality. And the third step involves the three-point bending tests in the INSTRON machine. Descriptions of the experimental details below include the geometric size of specimens, material selections for TWBs sheets, and experimental protocol.

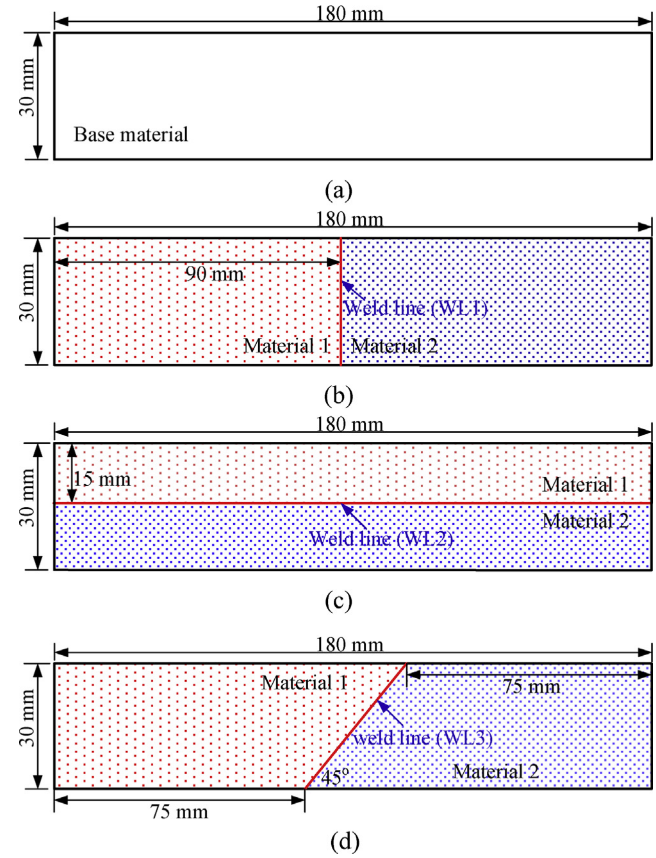

Fig. 1. Schematic configurations of base materials and TWBs specimens with three different weld orientations.

2.1. Geometry of TWB specimens

A typical TWB specimen is prepared by welding two or more different grades and/or thicknesses of base materials. The virgin TWB plates are of the same dimensions of 30 mm × 180 mm (Fig. 1(a)), while the thickness can vary for different TWB configurations.

In this study, three different orientations of weld lines (WL) are considered in order to explore their effects on mechanical behaviors as schematically shown in Fig. 1. In Fig. 1(b)–(d), these three weld lines are marked as WL1, WL2, and WL3, respectively, according to the different orientations. As a matter of fact, there are significant differences between the tensile strengths of TWBs and those of the joined base materials. The effects of weld line on the TWB mechanical behaviors are of considerable importance, which forms one of the key motivations of this paper.

2.2. Materials properties

The mechanical behavior of TWBs is affected by the thickness ratio, strength ratio, and weld conditions. In this study, the base materials used are two typical dual phase high strength steel sheets (namely DP600 and DP800). The chemical composition of the both base steels is listed in Table 1. Three different grade/thickness combinations are considered herein, marked as A: DP600/1.0 mm, B: