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Weld metallurgy and mechanical properties of high manganese ultra-high strength steel dissimilar welds

Martin Dahmen[a,]*, Stefan Lindner[b], Damien Monfort[c], Dirk Petring[a]

[a]*Fraunhofer-Institut for Laser Technology, Steinbachstrasse 15, 52074 Aachen, Germany*
[b]*Outokumpu Nirosta GmbH, 47807 Krefeld, Germany*
[c]*Polytech Nantes, 44306 Nantes Cedex 3, France*

Abstract

The increasing demand for ultra-high strength steels in vehicle manufacturing leads to the application of new alloys. This poses a challenge on joining especially by fusion welding. A stainless high manganese steel sheet with excellent strength and deformation properties stands in the centre of the development. Similar and dissimilar welds with a metastable austenitic steel and a hot formed martensitic stainless steel were performed. An investigation of the mixing effects on the local microstructure and the hardness delivers the metallurgical features of the welds. Despite of carbon contents above 0.4 wt.% none of the welds have shown cracks. Mechanical properties drawn from tensile tests deliver high breaking forces enabling a high stiffness of the joints. The results show the potential for the application of laser beam welding for joining in assembly of structural parts.

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1. Introduction

New ultra-high strength steels provide new lightweight opportunities and improve crash properties in future car bodies. By reducing the dead weight payload can be increased in vehicle construction for street and rails. Ultra-high strength steels with excellent deformation properties and intrinsic corrosion resistance are now commercially available. In order to utilize them different joining methods can be applied. As mechanical joining methods such as friction stir welding or self-piercing riveting are not applicable due to the high strength of the materials fusion

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* Corresponding author. Tel.: +49-241-8906-307 ; fax: +49-241-8906-121 .
E-mail address: martin.dahmen@ilt.fraunhofer.de

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welding should be applied with a strong limitation of the energy input. In the current contribution the effects of laser beam welding shall be investigated. Understanding the joining process as well as the response of the base materials on heat input is in order to create designs exploiting the full potential and fulfill the extensive requirements.

2. State of the art

The similar laser-welded TWIP (TWinning Induced Plasticity) steels joints exhibit a dendritic microstructure. Macrographs report a fully austenitic structure with grain coarsening in both, fused zone (FZ) and heat-affected zone (HAZ),where the latter is about 300µm wide, see the studies of Dahmen, Daamen and Hirt (2014) and Behm et al. (2013). A few publications dealing with the laser welding of TWIP steels to other grades are currently available. The main issue in these dissimilar welds is the appearance of chemical and/or phase inhomogeneities in the FZ since the multistage strain hardening of TWIP steels strongly depends on the composition (Mujica et al. (2009)).

The welding suitability of a martensitic stainless steel (1.4034) in as-rolled as well as in press hardened condition and the mechanical properties of welded joints have been reported by Janzen et al. (2015). Fatigue test results were displayed for the case of hot stamped tailored blanks. The fatigue strength of the welded specimen, determined by Wöhler tests, amounts to about 44% at $1 \cdot 10^7$ cycles compared with the fatigue strength of the base material. The results indicate a fatigue class of slightly above FAT 100. Quasi-static and dynamic tests according to the KS2 method reflect the behaviour of welds in hardened material for assembly. Load capacity and deformation are comparable to those of manganese boron steels. The scattering of the measurements ranges up to 9%. In all cases the joints failure mode is a brittle fracture in the weld zone. In as-rolled and in press hardened condition high hardeness at the fusion line, caused by bct martensite, requires a tempering treatment. For hot stamping this step can be. After hot stamping the heat-affected zone is transformed completely. Even the segregation lines are restored. A slight decrease of hardness in the former high-temperature heat-affected zone and in the fusion zone indicates the presence of a weld. The weld zone shows an increased content of retained austenite and consequently a decrease in hardness.

As the 1.4034 the grade 1.4678 is a derivative of 1.4301 (304) where nickel is replaced by manganese. The steel is fully austenitic and exhibits strong work hardening by the TWIP effect (Graessel (2000)). The original yield strength of 500 MPa can be increased to up to 1100 MPa by cold forming. Material at low and middle strength level show an excellent welding suitability whereas welding becomes difficult at a strength above approximately 800 MPa (Lindner (2014)). The work hardening is lost in the fused zone but can be regained upon deformation (Lindner, Gerhards, Dahmen (2015)).

Experiments conducted by Behm et al. (2014) have demonstrated the formation of a martensitic phase in the dissimilar welds of TWIP HSD60 to ferritic S420MC. Depending on the mixing ratio of HSD600 into S420MC, more or less martensite appeared. This shall be explained by the shift of austenitic former concentration into the weld pool. In this study, the most efficient microstructure to be obtained with overlap welds offering maximum shear forces, was that with the largest austenite fraction in the joining plane. This is achieved through full penetration weld, welding from TWIP to S420MC sheet with a speed of 3 mmin^{-1}. It was emphasized that mechanical shear strength of the dissimilar welds was not better than that of the weakest alloy.

Further studies on dissimilar butt joints TWIP Fe-22Mn-0.6C to a TRIP800 by Mujica et al. (2010) reported important segregation of manganese in the FZ and subsequent martensite formation. Manganese segregations in the form of C-Mn precipitates have also been reported along the dendrite boundaries in a TWIP/TRIP butt joint close to the TWIP side (Rossini et al. (2015)). Under tensile load, the latter butt joint fractured in the fusion zone. The resulting dissimilar joints exhibited poor mechanical strength.

3. Experimental

The austenitic TWIP steel is a new 1.4678 with a manganese content of 16.5 weight percent cold worked to a yield strength of 1 GPa. Partner materials under investigation comprise a metastable austenitic steel 1.4301 (304) and a martensitic stainless steel 1.4034 (420) in press hardened condition. Table 1 shows the chemical composition of the three materials. All values refer to ladle analyses taken during production of the sheet metal. Sheet thickness is 1.1 mm in the case of the manganese steel, 1.5 and 2 mm for the chromium-nickel and the chromium steel, respectively.

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