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Deformation behaviour of spot-welded high strength steels for automotive applications

S. Brauser*, L.A. Pepke, G. Weber, M. Rethmeier

BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

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ABSTRACT

Numerical simulation of component and assembly behaviour under different loading conditions is a main tool for safety design in automobile body shell mass production. Knowledge of local material behaviour is fundamental to such simulation tests. As a contribution to the verification of simulation results, the local deformation properties of spot-welded similar and dissimilar material joints in shear tension tests were investigated in this study for a TRIP steel (HCT690T) and a micro-alloyed steel (HX340LAD). For this reason, the local strain distribution was calculated by the digital image correlation technique (DIC). On the basis of the hardness values and microstructure of the spot welds, the differences in local strain between the selected material combinations are discussed. Additionally, the retained austenite content in the TRIP steel was analysed to explain the local strain values. Results obtained in this study regarding similar material welds suggest significant lower local strain values of the TRIP steel HCT690T compared to HX340LAD. One reason could be the decrease of retained austenite in the welded area. Furthermore, it has been ascertained that the local strain in dissimilar material welds decreases for each component compared with the corresponding similar material weld.

1. Introduction

In the last decade a change in body shell mass production has occurred in the automotive industry. In answer to the intensifying energy crisis and in order to meet customer requirements for automobiles such as weight reduction for energy saving and enhancement of passenger safety, new materials, e.g. advanced high strength steels (AHSS) have to be applied. These materials are gaining in popularity due to their high strength in combination with good ductility characteristics compared to traditional high strength steels, for example micro-alloyed steels [1–3]. An important AHSS representative is the so-called TRIP (TRansformation Induced Plasticity) steel dominated by a ferrite matrix with retained austenite, bainite and martensite as dispersed phases, offering excellent mechanical properties due to the transformation of retained austenite into martensite during plastic straining [2,4]. As a result, both strength and uniform strain increase owing to the appearance of a harder phase and to the additional local plastic yielding of the surrounding grains related to the transformation strain [5,6].

In the lightweight body shell mass production of automobiles, resistance spot welding is the most important joining technique. Typical vehicles contain about 3000–5000 spot welds. Therefore, good resistance spot welding behaviour must be one of the key characteristics of any steel grade to be used in automobile production [6].

For safe design of spot-welded body shell components, knowledge of the failure mechanism under static and fatigue loading is of main interest [6–8]. Typically, three different failure modes can occur in spot-welded structures, i.e. interfacial failure, plug failure and partial plug failure [6,9]. Of these, the plug failure is the desired failure mode in automobile industry. For example, Zuniga and Sheppard [10] as well as Lin et al. [11] studied the failure modes of lap-shear specimens using optical micrographs. Lin et al. [11] and Wung et al. [12,13] proposed failure criterions under combined three resultant forces and three resultant moments and under combined loads, respectively, based on experimental results. The verification of such models is difficult because of the limited available experimental test data. Further experimental work has shown that in the plug failure mode, stress is concentrated at the nugget circumference and leads to necking in the HAZ and base metal, respectively [14–16]. But, due to the localised joining zone and, hence, localised stress/strain in the spot welds, characteristic material values for the welded area are not available till today, especially for AHSS.

In order to investigate the failure mechanism in more detail, the plastic strain and the stress distribution near the nugget must be known [17]. However, for lap-shear specimens which are typi-

* Corresponding author. Tel.: +493081044103; fax: +493081041557.
E-mail address: stephan.brauser@bam.de (S. Brauser).

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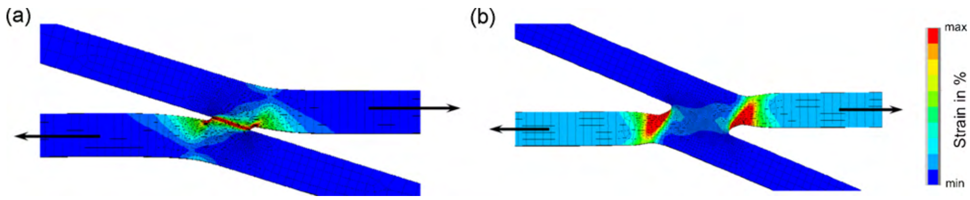

Fig. 1. FE-simulation of local strain behaviour of spot-welded shear tension samples via [6].

cal of spot-welded structures, analytical elastic–plastic solutions for stresses and plastic strains near the nugget are difficult to obtain. Therefore, researchers usually apply numerical methods. Numerous studies have been dedicated to elastic and elastic–plastic finite element analyses in order to characterise the fracture under static and cyclic loading, i.e. the fatigue behaviour. Radakovic and Tumuluru [6] proposed a simplified three-dimensional model of lap-shear specimens and determined the local strain behaviour for the interfacial failure and the plug failure, see Fig. 1. In the interfacial failure mode, the maximum local strain occurs in the nugget. In the plug failure mode, by contrast, the maximum local strain is found to be at the inner surface of the sheet and decreases in direction to the outer surface. These simulation results are in agreement with the experimental work discussed above. Lin et al. [17], Kan [18], Pan and Shepherd [19] as well as Satoh et al. [20] conducted two- and three-dimensional finite element analyses to examine the fatigue behaviour of spot-welded structures on the basis of plastic strain distribution near the nugget. Particularly with a view to validating and optimising such numerical simulations, local strain values are needed to calculate the real deformation behaviour and finally build up a realistic finite element model to analyse the fracture behaviour of spot-welded joints in automotive structures.

The objective of this study was to investigate the local surface deformation behaviour of spot-welded similar and dissimilar material welds in a shear tension test and to calculate local material data that can be used to validate numerical simulation of static and cyclic loading of spot welds. For this purpose, an optical strain field measurement system with high resolution was used. To investigate the effect of different stain values the fracture surface was characterised using scanning electron microscopy (SEM). Furthermore, on the basis of EBSD (Electron Backscatter Diffraction) measurements of the retained austenite content, explanation will be given for the local strain values of TRIP steel HCT690T.

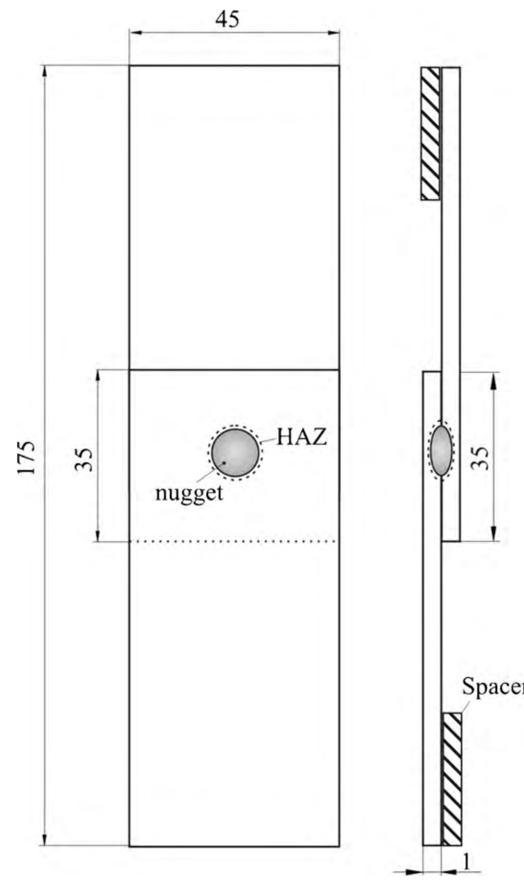

Fig. 2. Shear tension specimen dimension.

2. Experimental

In this study two different types of high strength steels were selected, including micro-alloyed steel HX340LAD and AHSS HCT690T. The micro-alloyed steel HX340LAD was chosen because of its extensive use in the automotive industry for similar material welds (SMW) and above all with regard to its application for dissimilar material welds (DMW), especially in conjunction with HCT690T. Table 1 shows an extraction of the chemical composition and the mechanical properties of the tested steels. Furthermore, the carbon equivalent (CE) characterised based on Eq. (1) [21] is listed, too. All steel grades offer a thickness of 1 mm and were hot dip zinc coated with an average weight of 140 g m^{-2}.

DMW dominate in body shell mass production. Therefore, in addition to the base metal combinations HX340LAD/HX340LAD and HCT690T/HCT690T, used as a reference, the combination HX340LAD/HCT690T will also be investigated.

$$CE = \%C + \%Mn/6 + (\%Cr + \%V)/5 + \%Si/15 \quad (1)$$

In this investigation, two sheet samples, 105 mm long and 45 mm wide, were overlapped by 35 mm and single spot-welded in the centre of the overlapped region, Fig. 2. These shear tension samples were used to calculate the local strain of conventional spot-welded structures.

Following EN ISO 14329 [9], spot-weld failure may occur in three modes: interfacial failure, plug failure and partial plug fail-

Table 1
Mechanical properties and an extract of the chemical composition of the base materials, measured via tensile test and Emission Spectrometry.

Steel grade	Yield strength (MPa)	Tensile strength (MPa)	*A* (%)	Alloying elements (wt%)						
				C	Mn	Cr	Al	Si	Fe	CE
HX340LAD	370	450	32	0.09	0.78	0.051	0.04	0.15	Balance	0.24
HCT690T	420	750	30	0.19	1.70	0.027	1.33	0.077	Balance	0.48