Failure analysis of spot welds in Advanced High Strength Steels

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Abstract.

Spot welding is the most common joining process in these components that includes local mechanical and thermal processing of the material. This local thermal treatment affects the microstructural and mechanical properties of the materials at the weld point. Therefore understanding the mechanical and microstructural properties of the material at the weld point is crucially important to predict the weld quality and service life of the products. The present research aims to better understand the deformation and failure mechanisms of AHSS used in the automotive industry with respect to their microstructural morphology in order to better predict the failure of the welded structures and crash worthiness of passenger cars. A new testing methodology was developed and uniaxial loading combined with 3D Digital Image Correlation technique was used to measure full field strain distribution within the weld zones. The results indicate that ductile fracture at the base material is the predominant failure mode for steel with lower strength, however interfacial and shear failure were mostly observed for automotive steels with higher strength.

Introduction

Resistance spot welding (RSW) is a primary joining method for sheet steels, being an inexpensive process that is carried out at high operating speeds. This is of large importance within the automotive industry, which continuously strives towards developing components as economically (low price, low timeframe) as possible. Spot welds are also highly dependable within vehicle frames as they act as fold initiation sites and aid the distribution of energy throughout it in the event of a crash, ensuring that the necessary safety requirements are met. A standard vehicle body contains anywhere between 2000 – 5000 spot welds [1].

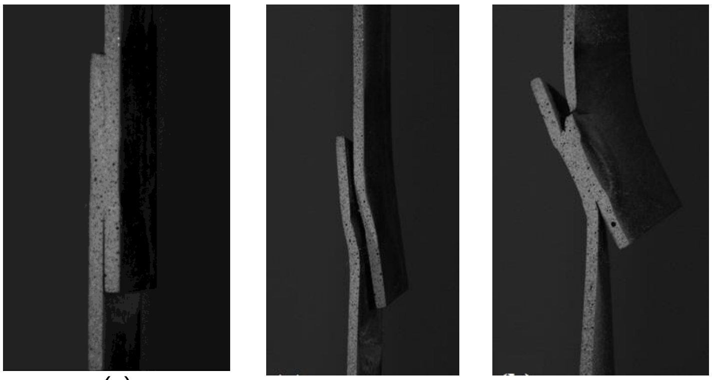
Resistance spot welding is a fusion welding process as a result of which the local microstructural properties of the material will be affected. Three different zones are created as result of the RSW process that will affect the deformation and failure characteristics of the welded structures. Therefore it is important to understand the effect of welding parameters on the local deformation and failure mechanisms of the welded part in order to predict their structural integrity and crashworthiness. The present research aims to develop a multi scale experimental framework to better understand the failure mechanisms of the RSW in advanced automotive steels and determine the effect of welding parameters on micro-mechanical behaviour of the materials at the weld section.

Experiments

Lap shear test samples were designed and manufactured from HX340LAD and DP1000 automotive steels. The two parts of the samples were initially welded at different welding current levels in order to investigate the effect of the weld nugget size on the structural integrity of the welds as well as the local deformation field at the onset of failure. The samples were then cut in half and machined using Electro Discharge Machining (EDM) to reveal the cross section of the welds and produced a reduced width zone to ensure the weld nugget is subjected to a uniaxial stress field. The samples were then prepared for the experiments combined with a stereo Digital Image Correlation system (VIC 3D) in order to measure the deformation and strain distribution during the loading. The measured strain maps were then linked to the microstructure of the samples at the failure zone.

Results

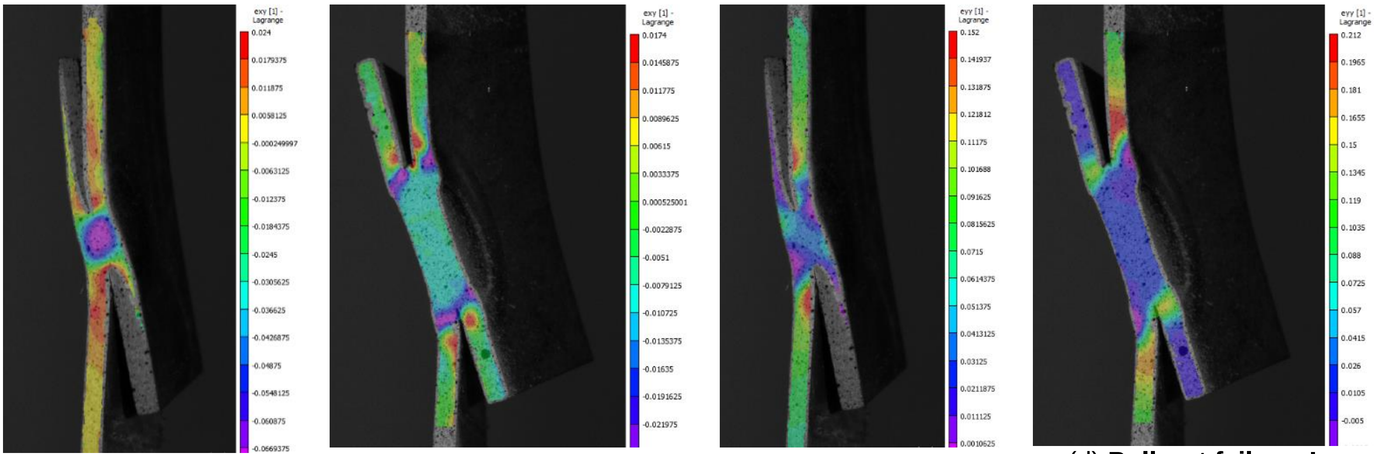
Deformation and failure modes of the tested samples were analysed with respect to the effect of the welding current level, and hence weld size. It has been found that the small weld undergoes a limited plastic deformation before the unset of failure for the interfacial failure mode (Fig 1b) while for the pull-out mode, observed for the larger weld, substantial plastic deformation occurs. In the latter case, the base metal fails due to the plastic instability followed by localised necking at the vicinity of the heat affected zone as it is indicated in Fig 1c.



(a) (b) (c)

Figure (1) (a) speckle patter produced on 1 mm thick HX340LAD samples to determine the failure mode on the spot welds due to uniaxial tensile loading, showing examples of (b) an interfacial failure for small weld size and (c) a pull-out failure for a large weld size.

Strain distribution in the HX340LAD samples are shown in Fig 2. Samples welded at low current (I_{min}) experience interfacial failure, while those welded at high weld current (I_{max}) showed pull-out failure. For the latter, plastic strains as large as 20% are observed before the localized necking in the heat affected zone. For the small weld, Fig2a shows that there is a shear strain concentration at the weld nugget before the interfacial failure. This can be used to determine a failure criteria for weld design in the corresponding materials. In contrast to the samples with interfacial failure, the shear strain is mostly concentrated around the heat affected zone (HAZ) in Fig 2b. This could be due to the fact that the samples experience a large gradient of microstructural morphology in this zone that affects the integrity of the localized mechanical properties. However the shear stress and subsequent shear strain concentration may not be large enough to trigger a failure at the HAZ.



(a) **Interface failure, I_{min}, ε_{shear}** (b) **Pull-out failure, I_{max}, ε_{shear}** (c) **Interface failure, I_{min}, ε_{normal}** (d) **Pull-out failure, I_{min}, ε_{normal}**

Figure (3) (a, b) shear strain(e_{xy}) and (c,d) normal strain (e_{yy}) distributions for the HX340LAD samples experiencing (a, c at minimum current) interfacial and (b,d at maximum) pull-out failure mode. The loading direction in all images are vertical and the e_{yy} strain corresponds to the strain in the loading direction

References

1. Pouranvari, M. and S. Marashi, *Critical review of automotive steels spot welding: process, structure and properties.* Science and Technology of welding and joining, 2013. **18**(5): p. 361-403.