Joining of aluminium using self-piercing riveting: Testing, modelling and analysis

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Abstract: The paper presents a study on identification and modelling of self-piercing rivet connections in aluminium. Failure loads of self-piercing rivets have been investigated under combined opening and shear static loading conditions using a new test set-up and simple specimen geometry with only a single rivet. These results were used to identify rivet model parameters in the code LS-DYNA using inverse modelling. Static and dynamic tests were conducted on double-hat sections made of aluminium sheets jointed with self-piercing rivets at the flanges to validate the chosen rivet model. The numerical analyses of these components provided a direct check of the accuracy and robustness of the numerical model.

Key words: Self-piercing rivet, connection, aluminium, testing, modelling, failure

A modern car structure may consist of several thousand rivet-type connections. Any failure in these connections plays an important role for the crashworthiness of the vehicle. Therefore accurate modelling of these connections is important for the automotive industry.

Self-piercing riveting has become an important joining technique in modern aluminium cars and an increasingly popular alternative to traditional spot welding. Self-piercing riveting is a method of joining two or more pieces of material using a rivet without a pre-drilled hole, Figure 1. This gives a cost reduction compared to the conventional riveting process. In the same way as spot welding it is necessary to have access to both sides of the joint since the back material has to be formed in a die in order to fasten the rivet. Self-piercing riveting is suitable for joining dissimilar materials, as well as coated and pre-painted materials, and can also be used to join some plastics to metals. Self-piercing rivets have shown to have good fatigue and crashworthiness properties and are used in 70% of the single point fastening of the Audi A8.

A literature survey on the behaviour and modelling of self-piercing rivet connections has shown a limited number of relevant articles. Some information is available from Henrob [1], Bollhoff [2] and the welding institute TWI [3]. They give some general information on the riveting process as well as the advantages of using self-piercing rivets compared with the most common joining techniques, such as spot welding. Numerical simulations of the self-piercing riveting process have been carried out by Khezri...
Westerberg [5] carried out finite element simulations of self-piercing rivet joints, i.e. peel specimens, while Stromstedt [6] performed analysis of self-piercing rivet lap shear joint specimens. Analysis of the self-piercing riveting process and design of control of a self-piercing riveting machine were carried out by O’Sullivan [7].

Lennon et al. (1999) [8] have compared the load-displacement responses of four types of mechanical connections in thin gauge steel, these are self-piercing riveting, press joining, pop rivets and self-tapping screws. Shear tests have been done on these four types of mechanical connections with sheet thicknesses 1.0, 1.2, 1.6 and 2.0 mm. The self-piercing riveting has shown a high-peak load, a high initial stiffness compared with the other connections and a high ductility as the rivet part of the connection links the parent metal components through a large displacement response range.

Several investigations are reported with respect to the behaviour and modelling of spot welds and punched rivets in steel.

Lee et al. (1998) [9] have studied the ultimate strength of resistance spot welds in mild steel subjected to combined tension and shear loads. An interesting test set-up and design of experimental procedure to statistically evaluate the interactive behaviour of spot welds under combined load was presented in their paper.

Lin et al. (2002) [10] reported work on the failure loads of spot welds under combined opening and shear static loading conditions. They used a different set-up for the tests of spot welds under combined load conditions compared to Lee et al. [9].

Langrand et al. (2001) [11] have presented a study on riveted joints for numerical analysis of aeronautical frames under crash loading conditions. They studied the influence of structural embrittlement due to the riveting process, the strength of a riveted joint under dynamic loading and the characterization of a simplified rivet element. Tests on single-rivet specimens were carried out to characterize macroscopic failure criteria under mixed-mode loading. A rivet model has been developed from the test results. The behaviour of an airframe assembled with 700 rivets was studied to validate this model.

The present paper deals with a complete study on identification and modelling of self-piercing rivet connections. The objective was to validate a numerical model of a self-piercing rivet connection with the finite element code LS-DYNA for crash analysis of a riveted structure modelled with shell elements including failure of the rivet connections. A complete study here means that the approach used was complete in the identification of material and model parameters required for the main analysis, i.e. double-hat sections made of aluminium sheets joined by self-piercing rivets at the flanges. The program was divided in three parts. In the first part, material tests were carried out for identification of parameters required in the numerical analysis. In the second part, failure loads of self-piercing rivet connections with only one rivet have been investigated under combined opening and shear static loading conditions using a new test set-up and simple specimen geometry. These results were used as input for the identification of the rivet model parameters using inverse modelling. In the third and last part, static and dynamic tests were conducted on double-hat sections made of aluminium sheets joined with self-piercing rivets at the flanges. The numerical analysis of this component provided a direct check of the accuracy and robustness of the numerical model, (validation).

**MATERIAL PROPERTIES**

The mechanical properties of the aluminium plates were obtained from uniaxial tension tests. Specimens were cut from three different directions of the plate: 0° (i.e. the rolling direction), 45° and 90°. The nominal thickness of the aluminium was 2.5 mm. Representative engineering stress-strain curves for all specimens are given in Figure 2, while the Young’s modulus E, the nominal proof stress s0.2 as well as the nominal ultimate stress su are given in Table 1. The data from each direction are based on three parallel tests. With respect to the stress level in the three