Materials and Design 54 (2014) 323–330

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Tensile strength and failure simulation of simplified spot weld models

Noman Khandoker [a,*], Monir Takla [b]

[a] Department of Mechanical and Aerospace Engineering, Monash University, Melbourne, Australia
[b] School of Aerospace, Mechanical and Manufacturing Engineering, RMIT University, Melbourne, Australia

ARTICLE INFO

Article history:
Received 15 June 2013
Accepted 19 August 2013
Available online 28 August 2013

Keywords:
Spot weld modelling
Non-linear finite element analysis
Material damage criterion

ABSTRACT

A simple model for spot weld joints is desirable in body-in-white automotive structures which contains thousands of them. Hence, comparative performance and failure prediction study of six simplified spot weld models in terms of their geometric and constitutive properties are presented in this paper. The stiffness characteristics of these models under tensile loading condition were compared with the experimental results. It was found that the current spot weld modelling practice in the automotive industry predict the strength with 45.33% of error. To simulate the joint failure a material damage criterion correlating ultimate tensile strength of material was implemented in the developed models. The comparative study with respect to the accuracy was also related with the computational cost incurred by the different models. Hence, suitable modelling conditions to design a finite element model for spot welded joints are established which is very simple to develop, relatively cheap in terms of computational costs but yet predicts reasonably accurate results.

1. Introduction

Spot welding is the most common joining process for automotive body-in-white structures due to its production convenience and cost effectiveness. Generally most of the automotive components are designed and tested in a virtual design environment by using finite element analysis which requires the correct representation of the physical body. Spot welds used for joining purposes behave like an individual identity which affects the value of empirical relationships like structural effectiveness, which is proposed by Schneider and Jones [1]. Hence it necessitates accurate representation of the spot weld joints in finite element models.

The simplest and widely used model to represent the spot weld itself is the coincident nodes or two point rigid beam element [2]. Sheppard [3] had modified the idea of using a single rigid beam element, by utilizing a number of rigid beams to represent the spot weld joint. Similarly several studies [4,5] have used a number of rigid beams (increased with the level of mesh refinements around the nugget) and different arrangement patterns to represent the spot weld nugget. Recently Dincer et al. [6] had reported that the spot weld model with nine rigid elements around the nugget provided the best result. But all these previous studies were limited within the elastic analysis range only.

Wang et al. [7] have developed another model of spot weld nugget to represent the joint connection in test coupon configurations. A maximum strain based failure criterion was used for the failure simulations in this study. Sawai et al. [8] have also proposed several simple approaches to represent the spot welds for closed top hat sections using rigid and elastic beam elements, constrained nodes and spring elements. A force based failure criterion originally proposed by Wung et al. [9,10] was incorporated in these models. But this failure criterion can be used until the failure loads become non proportional to the state of stress. Therefore this failure criterion defines failure of the spot welded joints within the elastic limit of analysis. Allanki and Kumar [11] modelled spot welded joint with beam element and the failure of the joint was modelled using notch stress value derived by Zhang [12,13]. The maximum load predicted by the model nearly matched the test data.

The objective of this paper is to develop simple but realistic spot weld joint models with experimentally verified failure criterion. Generally the quality of spot welds is tested by destructive testing methods [14–16]. For these destructive tests single spot weld on test coupons are used. Hence, to compare and judge the performances of different spot weld models a simple test coupon configuration is chosen for both the experimental and numerical analysis schemes of this paper. For simulating the over loading behaviour of the joint, the energy absorbance characteristics during failure have an important role to predict the deformation pattern. Besides the issue of computational efficiency for spot weld models were not addressed in any of the previous studies. Therefore, spot weld joint models simplified in terms of their geometric and constitutive properties with a realistic failure condition will be presented in this paper which can be replicated numerous times in automotive body-in-white structures.

* Corresponding author. Tel.: +61 3 99051088.
E-mail address: Khandoker.Noman@monash.edu (N. Khandoker).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.08.070

2. Experimental analysis

2.1. Materials

In this research a cold rolled ductile sheet metal with general purpose surface finish was used for making the spot welded test coupons. The chemical composition of the selected material is given in Table 1.

The mechanical material property characterisation was carried out by uniaxial tensile tests in a preloaded ball screw driven Instron machine. These characteristic results have been used as input material parameters in the developed finite element models. Dog bone specimens were prepared according to the specifications provided by ISO 6892 [17]. The thickness of the tensile test specimens was same as spot welded coupon thickness (1.2 mm). Three specimens were tested for each of the test speed configurations of 500 mm/min, 100 mm/min, 20 mm/min and 5 mm/min. Different loading rates were chosen to ensure correct repeatable quantification process by observing the gradual incremental changes in the stress strain relationship. The average true stress–strain tensile properties were calculated from the force displacement relationship and are presented in Fig. 1.

For the spot welding process a spot welding machine with rated configuration of 7.5 KVA, 18 amps with a supply voltage of 415 V – 50 Hz was used. The welding current was set to the maximum available level in this machine for a welding period of 50 cycles (1.0 s) and for a squeeze time of 70 cycles (1.4 s) for each of the fabricated test sample joints. Generally the quality of the resistance welds depends on the manufacturing process parameters [18,19]. But the variations of the joint dimensions with the manufacturing process variables were not considered in this study. Instead failure mode based desirable spot weld nugget diameter was calculated. Thereafter, it was cross checked whether the utilized manufacturing process parameters could obtain the previously calculated dimension. These are presented in the following sections.

2.2. U shaped coupon tension test

U shaped tension coupon was used to study the tensile strength of the spot welded joint. The tension test was performed utilizing special designed grip attached for quasi-static and dynamic loading condition. The grip consisted of coupon holders and supporting side cushions plates. The test set up is presented in Fig. 2. The side plates were attached with the aid of nut, bolt and washers so that the coupons do not slip during the testing.

All experiments were conducted in displacement control mode. The displacement was recorded from the cross head displacement of the testing machine. As a force transducer a 50 kN load cell was used to obtain the applied load data for these tests. AWS [20] recommended conducting such experimental tests at a speed of 15 mm/min to minimize the strain rate effect on the strength of spot welded joint. Therefore two different types of speed configurations were chosen to simulate both the quasi static and the dynamic loading conditions. The test speed for 5 mm/ min was chosen to represent the quasi static condition. Whereas 500 mm/ min test speed was chosen to represent the dynamic loading condition. For each testing speed configurations five specimens were used to represent the repetitive nature of the test results.

Table 1
Chemical composition of sheet metal.

Chemical properties	Carbon	Phosphorus	Manganese	Sulphur
wt%	0.04–0.06	0.005–0.02	0.2–0.26	0.008–0.02

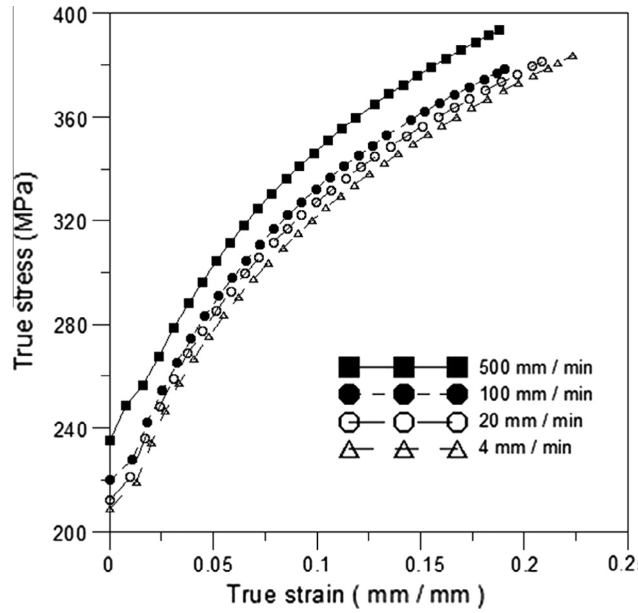

Fig. 1. True stress strain curve of sheet metal.

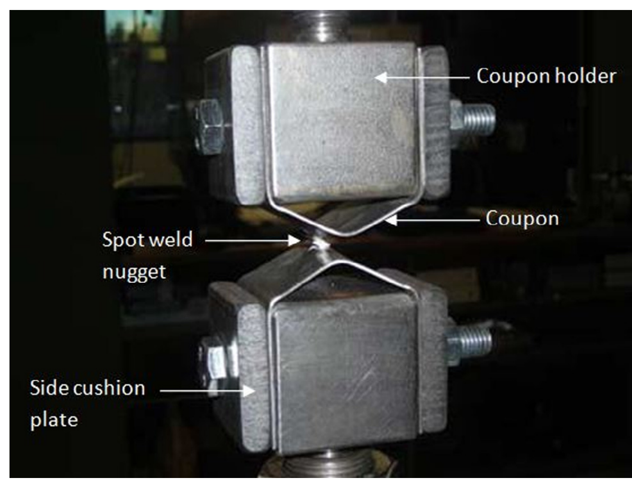

Fig. 2. Spot weld joint test setup.

Proper geometric dimensions of the test coupon may influence the failure process of the spot welded joint. Zhou [21] reported that the width of the test coupon is the most influential dimension. Wung [22] has determined the critical width dimension (to avoid distinctive variations) experimentally to be at least more than 35 mm. So for the present study the overall width of the U shaped coupon was chosen as 50.8 mm. The length of the welded section and of both the loading arms for the U tension coupon was 50.8 mm. The bend radius between the welded section and the loading arm was 3.175 mm. Prefabrication estimation of the spot weld nugget dimension was based on the mode of failure. In case of destructive testing procedures with the spot welded coupons, two distinctive failure modes are observed [23].

(A) "Nugget pull out failure" mode where the failure occurs around the spot weld nugget in the coupon sheet metal and it separates completely from the test coupon.
(B) "Interfacial failure" mode where the failure occurs inside the spot weld nugget and breaking it apart without damaging the test coupon.