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An expert system based on artificial neural network for predicting the tensile behavior of tailor welded blanks

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ABSTRACT

The forming behavior of tailor welded blanks (TWB) is influenced by thickness ratio, strength ratio, and weld conditions in a synergistic fashion. In most of the cases, these parameters deteriorate the forming behavior of TWB. It is necessary to predict suitable TWB conditions for achieving better-stamped product made of welded blanks. This is quite difficult and resource intensive, requiring lot of simulations or experiments to be performed under varied base material and weld conditions. Automotive sheet part designers will be greatly benefited if an 'expert system' is available that can deliver forming behavior of TWB for varied weld and blank conditions. This work primarily aims at developing an artificial neural network (ANN) model to predict the tensile behavior of welded blanks made of steel grade and aluminium alloy base materials. The important tensile characteristics of TWB are predicted within chosen range of varied blank and weld condition. Through out the work, PAM STAMP 2G® finite element (FE) code is used to simulate the tensile behavior and to generate output data required for training the ANN. Predicted results from ANN model are compared and validated with FE simulation for two different intermediate TWB conditions. It is observed that the results obtained from ANN are encouraging with acceptable prediction errors. An expert system framework is proposed using the trained ANN for designing TWB conditions that will deliver better formed TWB products.

1. Introduction

Tailor welded blanks (TWB) are blanks of similar or dissimilar thicknesses, materials, coatings, etc. welded in a single plane before forming. This welded blank is then formed like un-welded blanks to manufacture automotive components, with appropriate tooling and forming conditions. Applications of TWB include car door inner panel, deck lids, bumper, side frame rails, etc. in automotive sector (Kusuda, Takasago, & Natsumi, 1997; Pallet & Lark, 2001). Some of the advantages of using TWBs in the automotive sector are: (1) weight reduction and hence savings in fuel consumption, (2) distribution of material thickness and properties resulting in part consolidation which results in cost reduction and better quality, stiffness and tolerances, (3) greater flexibility in component design, (4) reusage of scrap materials to have new stamped products and, (5) improved corrosion resistance and product quality, etc. (www.ulsab.org). The forming behavior of TWBs is critically influenced by thickness and material combinations of the blanks welded; weld conditions like weld orientation, weld location, and weld properties in a synergistic manner. The impact of above said parameters on the tensile and forming behavior of TWB viz., stress–strain curve, forming limit strain, dome height, deep drawability, and weld line movement can be understood from the existing work (Bhagwan, Kridli, & Friedman, 2003; Chan, Chan, & Lee, 2003; Chan, Chang, Chan, Lee, & Chow, 2005).

Formability characteristics of TWBs is affected by weld conditions such as weld properties, weld orientation and weld location, thickness difference and strength difference between the sheets. Above said TWB parameters affect the forming behavior in a compounding fashion and hence it is difficult to design the TWB conditions that can deliver a good stamped product with more or less similar formability characteristics as that of un-welded blank. In this context, few research groups have aimed at predicting the formability of welded blanks by using different necking theories and Finite Element (FE) simulations. For example, Jie, Cheng, Chan, Chow, and Tang (2007) studied the forming behavior of 5754-O Al alloy sheets, where in the forming limit curve (FLC) of welded blanks with thickness ratio of 1:1.3 was experimentally evaluated and predicted using localized necking criterion based on Vertex theory. It is found from the analysis that the forming limit of the TWB is more closer to thinner material FLC and the experimental and predicted FLCs correlate well with each other. Similarly,

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Nomenclature

E	Young's modulus
ρ	density of the material
γ	Poisson's ratio
r_0, r_{45}, r_{90}	plastic strain ratios in three rolling directions
n	strain-hardening exponent
K	strength co-efficient
ε	true strain
σ	true stress
T_1/T_2	thickness ratio of TWB (thin/thick)
YS_1/YS_2	yield strength ratio of TWB (weak/strong)
n_w	weld strain-hardening exponent
YS_w	weld yield strength
W	weld width
TWB	tailor welded blanks
ANN	artificial neural network
FE	finite element
FLC	forming limit curve
DOE	design of experiments

Anand, Boudreau, Andreychuk, Chen, and Bhole (2006) investigated the limit strains of welded blanks made of IF steel of different thicknesses (0.75–1.5 mm). They have used modified Keeler criterion to predict the plane strain limit strain (FLD_0) in which average thickness and average strain-hardening exponent of the blanks constituting TWB was considered. The predicted FLD_0 is comparable with that of from experiments. Davies, Smith, Oliver, Khaleel, and Pitman (2000) investigated the limit strains of aluminium alloy TWB (1:2 mm thickness), where in the FLCs predicted by Marciniak–Kuczynski analysis are compared with the experimental results. Here the geometrical heterogeneity, i.e., the initial imperfection level, involved in the welded blank is modeled by using the strain-hardening exponent determined from miniature tensile testing together with the Hosford yield criterion, involving parameters $a = 8$ and $R = 1$ to determine a level of imperfection that exactly fits an FLD to each experimentally evaluated failure strains. The FLCs thus predicted are found to have good agreement with the experimental FLCs, except in the bi-axial stretching region. Recently Ganesh Narayanan and Narasimhan (2008a, 2008b) predicted the forming limit strains of laser welded blanks by using thickness gradient based necking theory incorporated into a FE simulation code PAM STAMP 2G®. It is found that the predictions are good in drawing region of FLD, with deviation in stretching region. From the above discussion, it is clear that one has to follow a limit strain theory in conjunction with numerical or analytical methods to predict the forming limit strains of welded blanks for different base material and weld conditions.

Similarly tensile behavior of welded blanks were also predicted for varied base metal and weld conditions. For example, Ganesh Narayanan and Narasimhan (2006, 2007) studied the influence of varied weld conditions on the tensile and forming behavior of welded blanks by numerical simulations. Here the main aim is to identify the sub domain of weld conditions with in which weld zone assumption is required instead of weld line assumption. Also the relative effect of TWB parameters on the forming behavior is studied. Similar work has been performed by Raymond, Wild, and Bayley (2004) also. It is clear from the above discussion that, in general, either numerical simulation or analytical models are used to predict the tensile behavior of welded blanks.

It is a known fact that the presence of thickness, strength heterogeneities and weld region deteriorates the formability of welded blanks in most of the cases. Designing TWB for a typical application will be successful only by knowing the appropriate thickness, strength combinations, weld line location and profile, number of welds, weld orientation and weld zone properties. Predicting these TWB parameters in advance will be helpful in determining the formability of TWB part in comparison to that of un-welded base materials. In order to fulfill this requirement, one has to perform lot of simulation trials separately for each of the cases which is time consuming and resource intensive. Automotive sheet forming designers will be greatly benefited if an 'expert system' is available for TWBs that can deliver its forming behavior for varied weld and blank conditions. Developing knowledge based system or expert system, especially in fields like material forming and deformation behavior, die design, casting design, machining processes, energy engineering, metallurgy, condition monitoring, etc. is of interest to manufacturing, design engineers and scientists for long time (Asgari, Pereira, Rolfe, Dingle, & Hodgson, 2008; Cakir & Cavdar, 2006; Dominczuk & Kuczmaszewskim, 2008; Ebersbach & Peng, 2008; Palani, Wagoner, & Narasimhan, 1994; Stein, Pauster, & May, 2003; Yazdipour, Davies, & Hodgson, 2008). Artificial neural network (ANN) modeling technique is found to show better prediction of any response variable that is influenced by large number of input parameters rather than conventional way of doing experiments. Application of ANN technique in predicting the formability of TWB will definitely be helpful in understanding and designing the TWB conditions that can deliver a better-stamped product.

The main objective of the present research scheme is to develop an 'expert system' for welded blanks that can predict their tensile, deep drawing, forming behavior under varied base material and weld conditions using different formability tests, material models, and formability criteria. It is decided to develop the expert system in conjunction with neural network technique. To start with, in the present work, ANN models are developed to predict the tensile behavior of TWBs. Global TWB tensile behavior like yield strength, ultimate tensile strength, uniform elongation, strain-hardening exponent and strength co-efficient are predicted for a wide range of thickness and strength combinations, weld properties and orientation by ANN technique. Standard tensile test sample is used to simulate the tensile test process using PAM STAMP 2G®, an elastic–plastic FE code. The sheet base materials considered for the present work are a low carbon steel grade and a formable aluminium alloy. ANN models are developed using a large data set obtained from simulation trials that can predict the tensile behavior of TWB within a chosen range of weld and blank conditions. Design of experiments technique is used to optimize the number of simulations. The accuracy of ANN prediction was validated with simulation results for chosen intermediate levels. An 'expert system design' has been proposed that will be developed to predict the formability of TWBs. The ANN models developed in this work will be used to construct the proposed expert system.

2. Methodology

The flow chart describing the methodology followed in this work is shown in Fig. 1. As depicted in the figure the first part of methodology involves simulation design and deals with the design of series of input property combinations and their values to study the effect of thickness difference, strength difference, weld properties, orientation on the tensile behavior of TWBs. In order to study with optimum simulations, design of experiments (DOE) using the Taguchi statistical design is followed. FE simulation models for predicting the tensile behavior of steel grade and aluminium alloy