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FEA comparison of high and low pressure tube hydroforming of TRIP steel

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ABSTRACT

The increasing application of hydroforming for the production of automotive lightweight components is mainly due to the attainable advantages regarding part properties and improving technology of the forming equipment. However, the high pressure requirements during hydroforming decreases the costs benefit and make the part expensive. Another requirement of automotive industries is weight reduction and better crash performance. Thereby steel industries developed advanced high strength steels which have high strength, good formability and better crash performance. Even though the thickness of the sheet to form the component is reduced, the pressure requirement to form the part during expansion is still high during high pressure hydroforming. This paper details the comparison between high and low pressure tube hydroforming for the square cross-section geometry. It is determined that the internal pressure and die closing force required for low pressure tube hydroforming process is much less than that of high pressure tube hydroforming process. The stress and thickness distribution of the part during tube crushing were critically analysed. Further, the stress distribution and forming mode were studied in this paper. Also friction effect on both processes was discussed.

1. Introduction

The automotive industry is increasingly interested in mass reduction of vehicles for improved fuel consumption. Hydroforming is a metal forming process that is now widely used as it can achieve weight reduction of about 30% compared to conventionally manufactured components [1]. At the same time automakers are increasingly exploring the potential to use advanced high strength steels, as they can also provide weight reduction without any reduction in other performance characteristics such as crash and durability.

The tube hydroforming process can be categorised into three pressurization systems: (1) low pressure hydroforming ($P < 83$ MPa) (2) multipressure hydroforming ($P = 69$–173 MPa) and (3) high pressure hydroforming ($P = 83$–414 MPa) [2]. Most research to date has focussed on high pressure hydroforming, particularly to improve the quality of the product and formability. For example local thinning and wrinkling can be prevented by oscillating the internal pressure in pulsating hydroforming. Through oscillations of the internal pressure, a uniform expansion in the bulging region was obtained, and thus the formability was improved by preventing the local thinning [3]. Accumulation of material in the expanding area by formation of useful wrinkles instead of dead wrinkles is an effective method to achieve good formability. This gives the modified process window for without wrinkles and useful wrinkles for hydroforming [4]. Yuan et al. [5] studied the influence of wrinkling behaviour on formability and thickness distribution in THF. Jain and Wang [6] developed a dual-pressure tube hydroforming process in which the plastic instability is delayed and the ductility of the metal is increased. Smith et al. [7] investigated tube hydroforming with a double-sided high pressure (DSHP) boundary condition which increased formability relative to that observed for the traditional single-sided high pressure (SSHP). To enhance the formability in whole tube hydroforming process, the feasible preform design method based on deformation history during forward loading was introduced [8]. Thinning values were compared to the simulation in order to validate the finite element model for the process. The FE model correctly predicts the THF process in terms of part shape and thinning distribution and hence simulation is a valid tool for such feasibility studies [9]. Different loading paths were studied to improve the formability of the tube [10]. Some of the literature has studied the effect of friction [11] on formability and an analytical model [12] to determine the friction coefficient was developed. According to the model, the friction coefficient can be calculated using the geometrical data from the deformed tube and materials properties without a force measurement.

There have been a number of studies by FEA to predict wrinkling, necking and bursting and compare with the experimental results [4,5,13–20]. Asnafi and Skogsgardh [21] proposed stroke controlled hydroforming to avoid the risk of buckling and fracture. Forming limit strains for loading with specifies fluid volumes are higher when compared to those with prescribed fluid pressure.

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Thus better formability may be attained in tube hydroforming by prescribing the fluid volume instead of pressure, in conjunction with axial feed [13]. Controlled forming pressure and end feed were applied to accurately form the tube. Faster pressure application compared to axial feed leads to excessive thinning and bursting, or fracture due to crack growth [14,16–20]. Combined internal pressure and axial feeding applied on X and T branch components [15,22] for anisotropic materials showed that the bursting pressure is increased with respect to an increase in anisotropic parameter *R*-value.

In comparison the research performed on low pressure hydroforming is limited and there is still insufficient knowledge to how effective design with the process. However, one of the attractions of this process is that it requires much lower pressures and it is of note that the high pressures above were for simple low carbon structural steels. For the advanced high strength steels the stresses required to deform the metal are much higher and hence the pressure requirements are further increased.

In this paper, a numerical comparison between low and high pressure tube hydroforming was carried out for the same final component. A ramp pressure curve was applied during the high pressure process, which allows a linear variation to the desired pressure with respect to time until the tube was completely formed. A constant pressure was applied for low pressure hydroforming. The die closing forces to form the tube were predicted along with the stress and thickness distribution. Further effect of friction for both processes was studied.

2. Material and methodology

2.1. Material

The steel used for the numerical investigation of the high and low pressure tube hydroforming processes was a commercial TRIP 780 grade. The true stress–strain curve determined in a conventional tensile test and used for simulation is shown in Fig. 1, while the mechanical properties are given in Table 1.

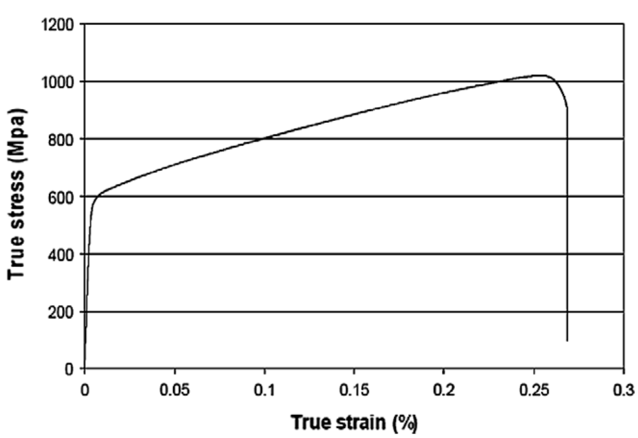

Fig. 1. True stress–strain curve determined in tensile tests for TRIP steel.

2.2. Methodology

In this study the high pressure tube hydroforming (HPTH) and low pressure tube hydroforming (LPTH), shown in Figs. 2 and 3,

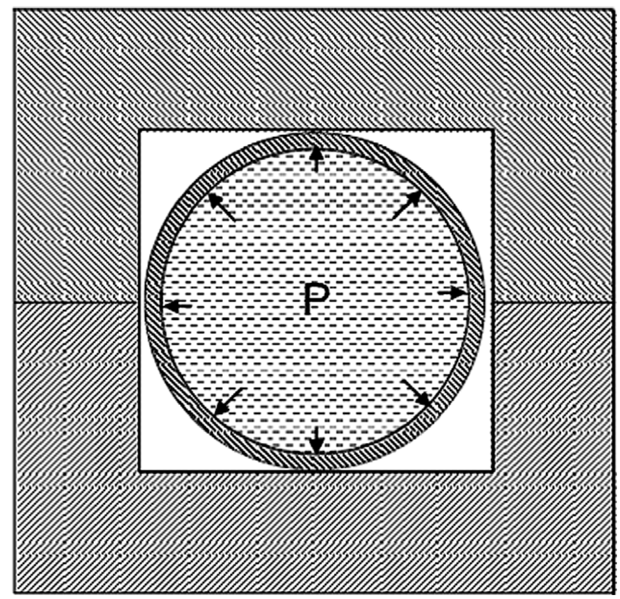

Fig. 2. Start of high pressure tube hydroforming (HPTH).

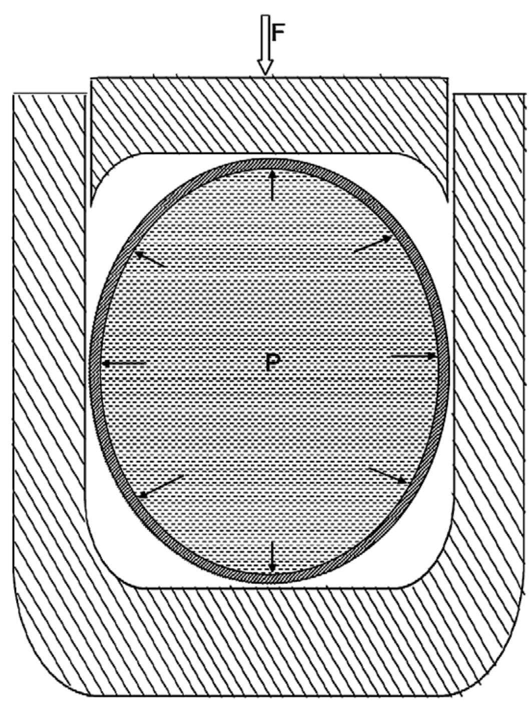

Fig. 3. Preform tube and start of low pressure tube hydroforming (LPTH).

Table 1
Mechanical properties of TRIP steel.

Designation	Mechanical properties				
	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	*K* (MPa)	*n*
TRIP (780 grade)	550	1020	26	1365	0.2263