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Short Communication

Experimental and numerical evaluation of forming limit diagram for Ti6Al4V titanium and Al6061-T6 aluminum alloys sheets

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ABSTRACT

The forming limit diagram (FLD) is a useful concept for characterizing the formability of sheet metal. In this work, the formability, fracture mode and strain distribution during forming of Ti6Al4V titanium alloy and Al6061-T6 aluminum alloy sheets has been investigated experimentally using a special process of hydroforming deep drawing assisted by floating disc. The selected sheet material has been photo-girded for strain measurements. The effects of process parameters on FLD have been evaluated and simulated using ABAQUS/Standard. Hill-swift and NADDRG theoretical forming limit diagram models are used to specify fracture initiation in the finite element model (FEM) and it is shown that the Hill-swift model gives a better prediction. The simulated results are in good agreement with the experiment.

1. Introduction

In recent years there has been growing demand for the production of hydroformed parts. Hydroforming of sheet metal makes use of hydraulic pressure to improve the basic deep drawing process. Hydroforming generally increases the draw ratio and minimizes the thickness variation of the formed part; in addition, other advantages associated with it are: requiring only one rigid tool and subsequently improving the quality of the products which as a result, lighter, cheaper, stronger, stiffer and less springback components are produced. Disadvantages include slow cycle times, highly polished dies and requirement of punch stroke/fluid pressure path characteristic to minimize wrinkling and rupturing occurrence [1–5].

Titanium alloy and aluminum alloy sheets are widely used in the automotive and aerospace industries due to continuous demands for the use of lightweight materials. During forming, these sheets are subjected to various types of strain. When the strain reaches/exceeds a critical value, different types of failures namely necking, fracture and wrinkling [6,7] occur.

Forming limit diagram provides the limiting strains a sheet metal can sustain whilst being formed. Laboratory testing has shown that lubrication, sheet curvature, thickness, orientation and material properties have effects on FLD [8–11]. The FLD is very useful in FEM analysis, die design optimization, die tryout, and quality control during production [12]. In recent years many techniques have been developed to evaluate FLD experimentally [13–16]. These include elimination of frictional effects between tool and material, the flatness of the blank surface and using parameters obtained from conventional tensile testing to determine FLD.

Moreover, with the increase of computational techniques, several researchers have proposed numerical models to predict the FLDs. Ductile fracture criterion to predict the forming limits was used. Based on these criteria, the occurrence of ductile fracture is estimated using the macroscopic stress and strain that occurs during deformation [17–20]. Other models have also been proposed: diffuse necking by Swift [21], localized necking introduced by Hill [22], the thickness imperfection model developed by Marciniak and Kuczynski [23] and the vertex theory brought forward by Stren and Rice [24]. However, predicting the FLD requires complex calculations and this will limit their use in practical applications. Furthermore, a general model that can be applied for various sheet metals has not been proposed.

In this paper, a new hydroforming die, assisted by a floating disc which combines hydrodynamic deep drawing and viscose pressure forming is used. With this new arrangement the normal blank holding force and chamber pressure will be halved, and the punch force has been decreased. Uniaxial tension tests were used to obtain material properties. For a better understanding of the forming behavior of these materials FLD diagrams for Ti6Al4V alloy and Al6061-T6 alloy sheets have been studied. The effects of process parameters on FLD diagram have been evaluated and simulated using ABAQUS/Standard. Hill-Swift [25] and NADDRG [26] theoretical forming limit diagram models are used to specify fracture initiation in the finite element model and it is shown that the Hill-Swift model gives a better prediction.

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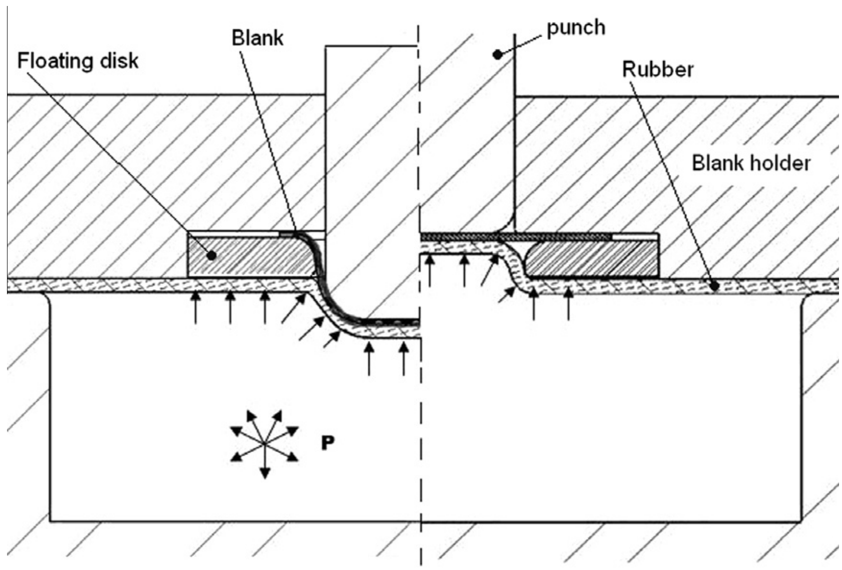

Fig. 1. The hydroforming process assisted by floating disk.

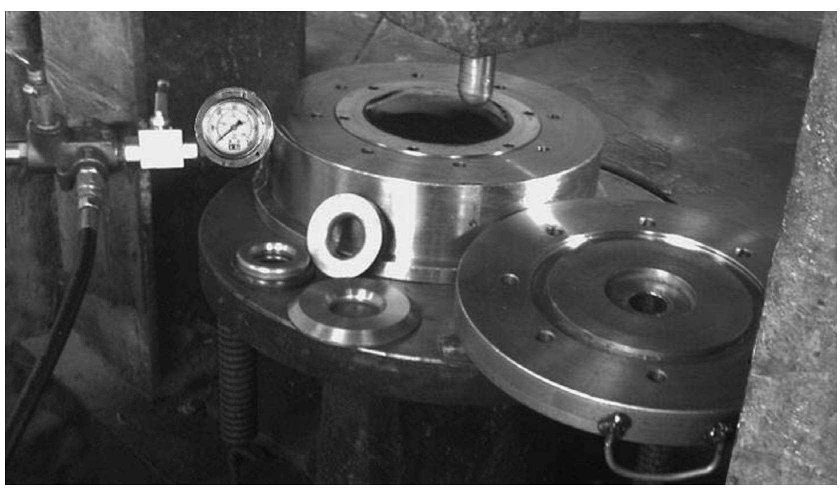

Fig. 2. Hydraulic press & die.

2. Experimental procedure

2.1. Hydroforming die

Hydroforming assisted by a floating disc is a new method that can simplify the tools used for hydroforming and decrease the cost of the process. With a floating disk, two sides of a blank will suffer equal friction force due to the normal blank holding force, in contrast to hydrodynamic deep drawing and viscose pressure forming processes, in which the medium in the chamber is in contact with one side of the blank. Therefore, the normal blank holding force and chamber pressure will be halved, and the punch force can consequently be decreased. Moreover, the die is very simple. The need for an independent hydraulic system to control the blank holding force and a complicated control system to adjust the gap between the die and blank holder can be avoided.

Fig. 1 shows the tools used. These are; punch, blank holder, pressure chamber, rubber diaphragm and floating disk. The diaphragm and the disk at the bottom can move up and down due to the pressure of the viscous medium in the chamber. The blank is placed between the blank holder and the floating disk. The blank holding force (BHF) due to the pressure of the chamber and the area of the floating disk can press the blank tightly to the blank holder. As the punch moves down, the process starts. A control valve regulates the liquid flow and the blank holding force can consequently be controlled.

All of the experiments were carried out using a 250-ton hydraulic double-action press. Fig. 2 shows the equipment used and Table 1 gives the dimensions of the tools used for this process. For

Table 1
Tool dimensions.

Parameters (mm)	Values
Punch diameter, d	40
Inside die (disk) diameter, d_d	43.5
Punch nose radius, r_p	10
Die entrance radius, r_{die}	5
Inside blank holder diameter, d_c	40.2
Blank holder entrance radius, R_c	2