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An experimental investigation into the warm deep-drawing process on laminated sheets under various grain sizes

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ABSTRACT

It has been proved by many researchers that increasing the temperature in warm deep-drawing process of single layer sheets decreases the forming load, however, this phenomenon is not necessarily the case in warm deep-drawing process of laminate sheet. The objective of the present paper is to carry out a comprehensive investigation on warm deep-drawing process on laminated sheets experimentally. Based on the results of this study, it can be observed that by raising the temperature, variation of forming load more depends on blank holder force (BHF). In this study, thinning and wrinkling in Al 1050/St 304 and Al 5052/St 304 samples for each layer in warm deep-drawing process are evaluated individually. In addition, the effects of various grain sizes, blank temperatures and sequence layer on forming load are investigated. In order to carry out a comprehensive survey of warm deep-drawing; three blank temperatures namely, 25 °C, 100 °C and 160 °C are examined. Furthermore, to achieve various grain sizes, the aluminum sheets are annealed at 350 °C, 400 °C and 450 °C for 1 h. Finally, several tests are conducted to obtain the influences of grain size on some material characteristics such as stress, elongation and friction coefficient.

1. Introduction

Nowadays, warm deep-drawing process, as one of the most applicable sheet metal forming processes, has been attracting more and more attention because of their application advantages such as manufacturing of complex shape, improved formability, reduced production time and controlled plastic flow. Because of re-crystallization, the temperature is one of the notable points during the forming process. The temperature during the warm deep-drawing should be kept below the re-crystallization temperature. The temperature affects the material behavior during the process and accuracy of finished parts. In comparison to hot forming processes, warm forming requires higher forces for deformation because of the greater material flow stress [1,2].

Due to a wide range of application and unique characteristics of laminates sheet such as high strength, low density, damping covering structures and corrosion resistibility researcher are paying more attention to laminated sheets. Therefore, they are used in various industrial fields such as aerospace, automobile, chemical and electrical industries. A laminated sheet consists of two or more metals with different material combinations and different thicknesses. In general, laminated sheets can be made by several processes, such as explosive bonding, adhesive bonding or cold and hot roll bonding. The laminated sheets formed by warm deep-drawing process can be used in manufacturing of parts with different inner and outer conditions for instance, corrosion, wear resistance and thermal and electrical conductivities [3,4].

In recent years, many researchers have dealt with deep-drawing process of laminated sheets. Despite that, the investigations carried out on laminated sheet deformation during the deep drawing process, were surveyed only in room temperature. Deep-drawing process of laminated sheet Fe/Al was simulated by Takuda et al. [5]. The fracture initiation and the forming limit were successfully predicted by using the ductile fracture criterion and compared with experimental observations. They found that the drawing ability and LDR of aluminum alloy sheet can be improved by laminated sheet where Fe layer was set on the punch side. Parsa et al. [6] investigated the behavior of Al/St laminated sheets during deep-drawing, direct and reverse redrawing processes by simulations and experiments. It can be found that to achieve the highest LDR in direct and reverse redrawing, the thickness ratio should be about 1/3 (one-layer of aluminum and three-layer of stainless steel) and the setting conditions were opposite to each other. The wrinkling of laminated sheets (Al/St) in the deep-drawing process, were studied through an analytical method, numerical simulations and experiments by Morovvati et al. [7]. Moreover, influence of stacking sequence of the layers on forming load and wrinkling were demonstrated. The forming force where the aluminum layer was stuck to the upper layer was greater than the one the stainless steel layer was stuck to the upper layer. Nevertheless, thinning and lubrication effect on forming load were not surveyed. Influences of several parameters in deep-drawing process of laminated sheets (Steel/Brass), including staking sequence of layers, lubrication and thinning were presented by

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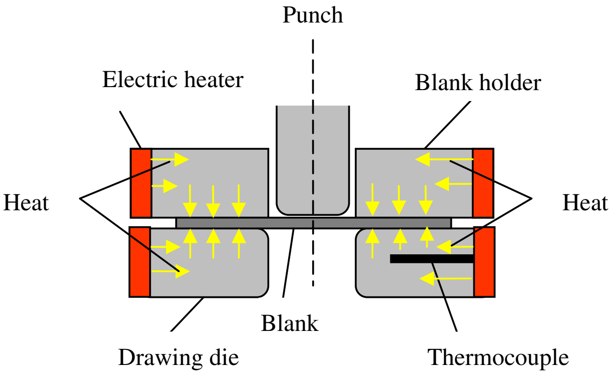

Fig. 1. Schematic representation of the equipment for the deep-drawing test.

Table 1
Dimensions of various parts of the deep-drawing die set.

Dimension	Value (mm)
Punch diameter	65.5
Die inner diameter	70
Die outer diameter	153.5
Punch and die profile radius	5
Blank holder inner diameter	67
Blank holder outer diameter	164
Clearance	2.25

Table 2
Chemical composition (wt.%) of aluminum alloys and stainless steel.

Element	Al 1050	Al 5052	St 304
Si	0.12	0.25	0.44
Fe	0.28	0.40	70.55
Cu	0.02	0.10	0.14
Mn	0.02	0.10	1.38
Mg	0.02	2.82	–
Zn	0.011	0.10	–
Ti	–	0.15	–
Cr	–	0.10	19.97
AL	99.49	95.98	–
V	–	–	0.12
Ni	–	–	7.00

Atrain and Fereshteh-Saniee [8]. They showed that the specimens with steel in the upper layer need higher forming load for deformation compared to those of brass in the upper layer. Rajabi et al. [9] investigated the deep-drawing process of two thermoplastic metal-composite laminates. They showed that the BHF had a significant effect on the wrinkling of laminates while the temperature had only a significant effect on the maximum forming load.

Nowadays, aluminum alloys are desirable for aerospace and automotive industry because of: (i) excellent high-strength to weight ratio, (ii) superior corrosion resistance, (iii) high weldability, and (iv) recyclability of alloys (for instance, recycling potential of the aluminum alloy products is much better than the ferrous metals). However, the formability and surface quality of final products are diminished when those are produced in room temperature. Consequently, warm forming is used to enhance the formability and the surface quality [10].

Warm deep-drawing for aluminum alloys has already been reported by many researchers. Bolt et al. [11] conducted warm deep-drawing experiments on various aluminum alloys (1050, 5754-O and 6016-T4) between 100 C and 250 C using box shaped and conical rectangular dies. Their study showed that raising temperature increased formability. Takuda et al. [12] reported the simulation results for cylindrical deep-drawing of aluminum alloy at elevated temperatures and observed that the necking site and forming limits were successfully predicted by simulation. The warm deep-drawing on aluminum sheet was investigated by Van den Boogaard and Huetink [13]. The behavior of aluminum was modeled using Hill 48 yield, von Mises criterion and Bergstrom hardening model and it was concluded that the Hill 48 criterion could not suitably predict the thinning. Palumbo and Tricaico [14] clearly demonstrated that the formability with a partial heating in die or blank holder area was much better than those obtained with homogeneously heated tools. In addition, the results showed that the temperature in the blank center strongly affects the formability and punch force. Nevertheless, distribution of thickness was not considered. Kim et al. [15] developed analytically a non-isothermal model for warm deep-drawing using various punch speeds and temperatures. The punch speed and temperature had noticeable effect on LDR and thickness distribution. Therefore, with increasing the punch speed LDR decreased. Furthermore, when the punch and die temperatures were 25 C and 180 C respectively, thickness distribution was more uniform than when they were 180 C. The effects of blank holder force on the wall thickness distribution and wrinkles in deep-drawing process of Al 1050 were investigated by Ibrahim Demirci et al. [16]. Their studies showed that for the blank holder force between 0.65 MPa and 10 MPa, the process was carried out

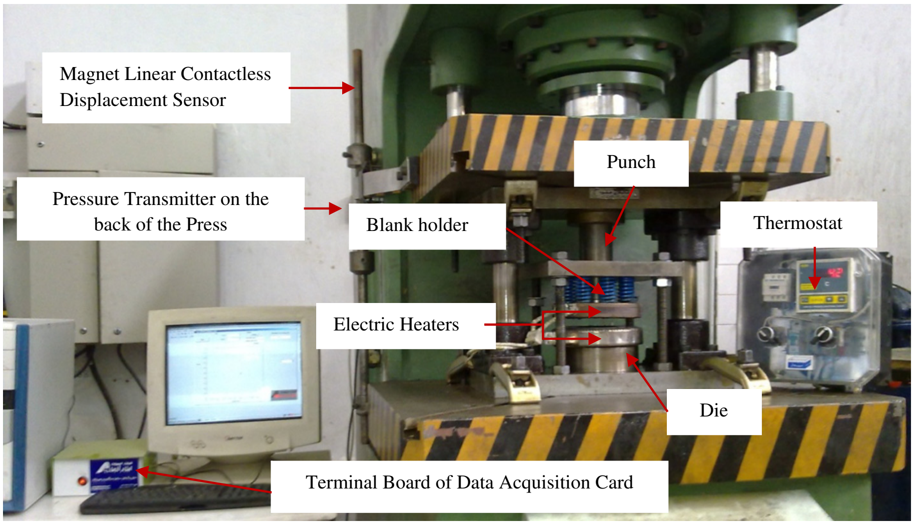

Fig. 2. Experimental test equipment.