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EXPERIMENTAL RESEARCHES REGARDING THE STRUCTURAL MODIFICATIONS SUFFERED BY PARTS OBTAINED BY INCREMENTAL SHEET METAL FORMING

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Abstract: *The current paper refers to one of the new non-conventional forming processes for sheet metal, namely incremental forming. Incremental sheet metal forming represents a complex metal forming process, at which, as compared to the classical stretch forming process, the kinematics comprises beneath a movement on vertical direction also a movement in the blank's plane. This paper targets the study of micro structural modifications suffered by parts obtained by incremental sheet metal forming.*

Key words: *non-conventional forming process, incremental forming, hemispherical punch, micro structural analysis, experimental researches.*

1. INTRODUCTION

The incremental sheet forming process represents a modern method of cold forming of relatively recent date applicability and in an incipient stage because of the lack of results obtained from systematic researches. At the process of incremental sheet forming (Fig. 1), the deformation is achieved by a punch that comes in partial contact with the surface of the blank.

For the achievement of the form of the part, one of the active elements (generally the punch) will have an axial, continuously or gradual (incremental) movement on vertical direction, while the other (the die) will perform a horizontal plane movement. The flexibility of the process is high, as with the same punch and the same die, according to the movements imposed to the active elements and using the same machine tool, there can be obtained many shapes.

Variations of incremental sheet forming have long been practiced in small workshops and private enterprises, and some early concepts of incremental sheet metal forming were patented in the USA by Roux in 1960 and Leszak in 1967. Academic research began in the early 1990's in Japan, by Iseki and Tanaka, and more recently has attracted increasing interest in Europe and Canada.

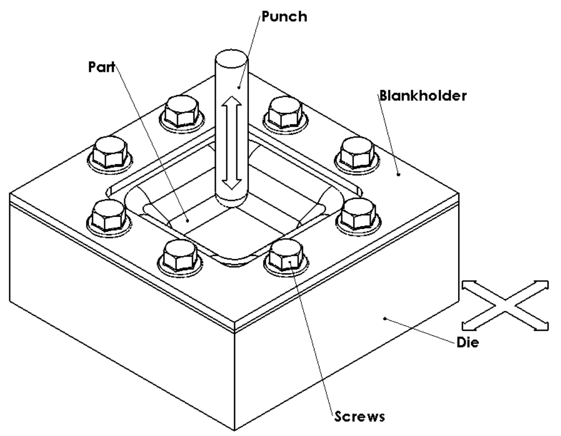

Fig. 1. The principle of incremental sheet forming process.

A comprehensive review of the development of the process is given by Jeswiet et al. (2005). In recent years, researches in the domain of incremental forming were focused on determining of forces in the process [2, 4], and on determining the precision and quality of parts obtained by this method [1, 3]. Furthermore, numerical simulations of the procedure were realised, which allowed also determining the springback [5].

The current paper aims to study the microstructural modifications that appear during incremental forming. We would like to emphasise the originality of this paper, since on world level there are no other researches that refer to this otherwise interesting and important subject.

2. EXPERIMENTAL LAYOUT

The experiments were carried out on an experimental installation (Fig. 2) realized as an electro-mechanical structure built as a manufacturing mini-centre with 2 1/2 axes. The experimental layout reproduces the forming system taken into account in the numerical simulation.

We have used 9 individual, circular-shaped blanks with a diameter D = 120 mm and different thicknesses.

Fig. 2. Experimental layout.

One single active plate was used, with a square active area, with a fillet radius R_{pl} = 6 mm and with the square's length L = 80 mm. The forming speed was constant throughout the experiments: v = 25 mm/min.

The microstructure of such parts depends, firstly, on the blank's microstructure; steel sheets for deep drawing, made of rimming steel, rolled under optimal conditions first hot and then cold, have a ferritic-pearlitic structure.

The material of the blank that will be subjected to the incremental forming of metal sheets is a steel of type DC03 SR EN 10130:2000, whose chemical composition was determined as follows:

- 0.10 % C;
- 0.43 % Mn;
- 0.017 % Si;
- 0.035 % P;
- 0.32 % S.

In order to better emphasize the specific phenomena taking place in the elementary work space at the processing through incremental forming of metal sheets, a micro structural analysis of the parts processed under various technological conditions was carried out. Due to the fact that the part's material is a carbon steel for forming operations (a mild steel), the idea of testing the part's micro hardness in various areas was abandoned, as the micro hardness variation would not have been significant.

The studied samples were prepared by means of the typical operations for such a study, namely cutting, grinding, polishing and metallographic etching. The cutting was done on the longitudinal direction of the formed samples, they then being embedded in Duracrol (a metacrylic self-polimerisable resin), as can be seen in Fig. 3.

The grinding was done successively with abrasive papers with grain sizes of 220, 280, 320, 400, 500, 800 and 900 respectively, while the polishing was done with felt wetted with an emulsion of synthetic diamond powder Dia-Sol with a grain size of 0.25 / 0.5 in diluting solution Dilo-Sol and water.

The revealing of the metallographic structure was done by etching the samples with natal etchant (3 % nitric acid concentrated 1.40 in ethylic alcohol solution) and the analysis of the structural transformation with the help of a metallographic microscope Neophot 21 (Fig. 4).

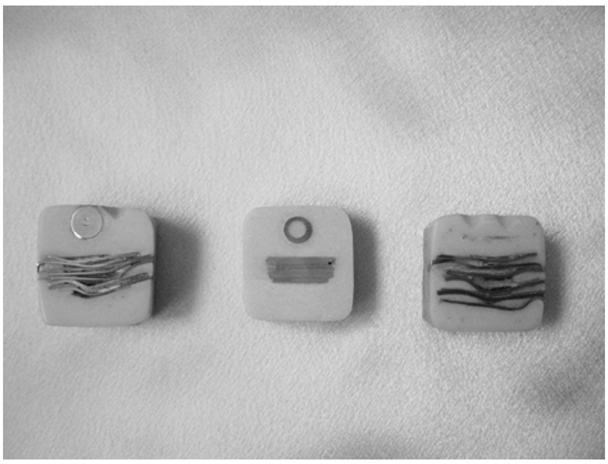

Fig. 3. The embedded samples.

Fig. 4. The Neophot 21 microscope used for the micro structural analyses.

3. EXPERIMENTAL RESEARCHES

In a first stage, the micro structural behaviour of the DC03 deep drawing steel sheet with a thickness of 0.5 mm was studied, this sheet being the most influenced by anisotropy due to its reduced thickness. Of the above-mentioned sheet metal, there were realised several parts with two punch dimensions (D_p): 12 and 20 mm, respectively, penetrating into the material at two different depths (h): 6 and 10 mm, respectively. The parts were realized using a square die with the radius of 6 mm. After the punch's penetration into the material, they execute a linear movement parallel to the die's edge on a distance of 40 mm.

In a second stage, the micro structural behaviour of the deep drawing steel sheet with a thickness of 1 mm was studied. In this case, only the punch's penetration depth was varied, between 6 and 10 mm, respectively.

In order to be able to assess the material's micro structural behaviour in the case of incremental forming of metal sheets, the microstructure of the crystalline structure was studied also before the forming operation. Fig. 5 presents the initial state of the 0.5 mm sheet and Fig. 6 the one for the sheet of 1 mm thickness.For the 0.5 mm sheet there can be noticed an accented elongation of the grains even before the forming operation, due to the previous rolling process.

Figures 7 and 8 present the microstructures in the most stressing case for the 0.5 mm sheet (when the forming degree is maximal), at the processing with a punch with D_p = 12 mm and a depth of 10 mm (Fig. 7 for the part bottom area and Fig. 8 for the area of the filleting radius). Figures 9 and 10 present the microstructures in the less stressing case for the 0.5 mm sheet (when the forming degree is minimal), at the processing with a punch with D_p = 20 mm and a depth of 6 mm (Fig. 9 for the part bottom area and Fig. 10 for the area of the filleting radius).

Figure 11 presents the case of a part of 1 mm thickness, for which the penetration depth of the deep-drawing punch is 10 mm, while Fig. 12 presents the case of a part of 1 mm thickness, for which the penetration depth of the deep-drawing punch is 6 mm. In both cases, the punch diameter was of 16 mm.

Fig. 5. Initial microstructure for the sheet g = 0.5 mm (× 125).

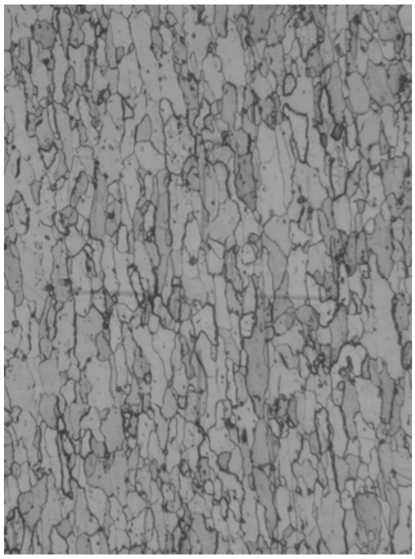

Fig. 6. Initial microstructure for the sheet g = 1 mm (× 125).

Fig. 7. Deformed microstructure in the area of the part bottom, for the case g = 0.5 mm, D_p = 12 mm and h = 10 mm (× 125).

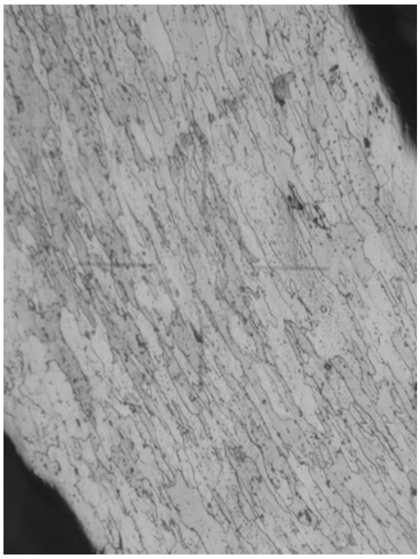

Fig. 8. Deformed microstructure in the area of the fillet radius, for the case g = 0.5 mm, D_p = 12 mm and h = 10 mm (× 125).

Fig. 9. Deformed microstructure in the area of the part bottom, for the case g = 0.5 mm, D_p = 20 mm and h = 6 mm (× 125).

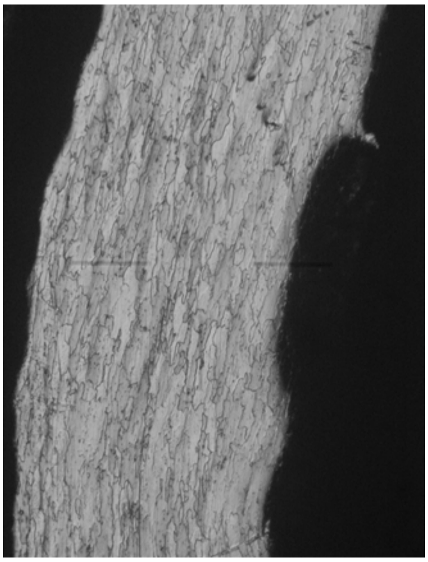

Fig. 10. Deformed microstructure in the area of the fillet radius, for the case g = 0.5 mm, D_p = 20 mm and h = 6 mm (× 50).

Fig. 11. Deformed microstructure in the area of the fillet radius, for the case g = 1 mm, D_p = 16 mm and h = 10 mm (× 125).

Fig. 12. Deformed microstructure in the area of the fillet radius, for the case g = 1 mm, D_p = 16 mm and h = 6 mm (× 125).

There can be noticed an elongation of the grains determined by the material's plastic forming, elongation that increases with the increasing forming degree. Thus, for parts with thicknesses of 0.5 mm, the grains' elongation is the greater, the higher the part is and the smaller the punch diameter is. Also, the grains are less elongated in the area of the part bottom compared to those in the fillet area, area which coincides with the one of the punch's penetration into the material and which is subjected to the highest stress.

For the part with the thickness of 1 mm there can be noticed the same tendency of grain elongation function of the increasing part depth and of the decreasing punch diameter, but there can be also noticed that the grains are less elongated compared to the thinner part (g = 0.5 mm), a fact that could be related also to the crystalline grains' initial state.

For the part made of normalised steel sheet, the grain elongation is very small, the grains' state being close to the one of the non-deformed sheet.

4. CONCLUSIONS

Generally, the grain size has a strong influence on the technological characteristics of steel, the fine grains providing higher values of the tensile strength, yield strength and tenacity, as well as a lower tendency towards deforming and fissuring during quenching. On the other hand, coarser grains provide a higher quenchability but determine fragility and lower mechanical characteristics.

The assessment of the grain size was done by counting, at the magnification of 100×, on the matted glass of the microscope Neophot 21, in a circle of diameter 79.8 mm (corresponding to a real part area of 0.5 mm^2), according to SR ISO 643.

The measurements carried out have led to determining the ferrite grains size at sizes between 6 and 9 both for parts obtained from heat treated blanks and for parts obtained from untreated blanks.

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