INVESTIGATION OF THE STRUCTURE AND PROPERTIES OF INCONEL ALLOYS AFTER HYDROMECHANICAL FORMING

Monika HYRCZA-MICHALSKA

Silesian University of Technology, Faculty Materials Engineering and Metallurgy, Katowice, Poland, EU,
monika.hyrcza-michalska@polsl.pl

Abstract

The sheet metal pressing structures produced by hydromechanical forming of nickel superalloys were analyzed to determine effect of plastic deformation on the structure and mechanical properties of finished products. The Inconel 625 nickel-alloy sheet metal was extruded with liquid in the form of cones. The drawpieces were mechanically divided by cutting into main cross sections. An analysis of local deformation distributions, structure deformation level and distribution of alloy components on these sections were evaluated. It has been shown that the plastic deformation carried out by liquid forming (hydroforming) or by a liquid through an elastomeric membrane preserves the original structure and properties of the sheet metal input level, only with the effect of work hardening of tested alloys.

Keywords: Inconel 625, nickel superalloy, hydromechanical forming, structure deformation, drawability

1. INTRODUCTION

The requirements for pressed products in the aerospace and automotive industries are significant. Structures of such shells type have more and more complex shapes, which results from the aerodynamic needs of shape, structural strength and reduction of the mass of the structure [1]. Designing the production ofsuch type elements is supported by computer modeling and numerical simulations. As a result, it became possible to use advanced and complex manufacturing technologies, such as hydromechanical forming [2, 3] and pressing at elevated temperature to obtain extrusions responsible for the safety of users. Not economic aspects but mainly application requirements of this type of products have become the determining factor in the choice of technology for their production. To define the supply of technological plasticity, which has a sheet blank, it becomes important to recognize the degree of deformation or percent of true strain during and after forming the final product. This work presents the effect of plastic deformation influence on the structure and mechanical properties of finished products. The research concerned a heat-resistant and creep-resistant material - an Inconel nickel super alloy.

2. HYDROMECHANICAL FORMING

2.1. Manufacturing process

Looking for modern waste-free, energy-efficient manufacturing techniques, hydroforming has the potential worth to use for the production of high quality stamped elements. Cold forming using conventional dies of light alloys thin sheets brings many problems, because of their limited drawability, susceptibility adhesion to the tools, high resistance or other their properties. Hydroforming is manufacturing techniques which can be now designing and control using computer aid techniques and numerical simulation [2, 3]. In this regard, the manufacturing process using hydromechanical forming elastomer membranes and working liquid - oil was analyzed. This technology is characterized by a favorable, spatial mechanical condition occurring during the deformation of the charge materials and limiting the influence of friction on the contact conditions of the charge with the tools. Pressing tests were carried out in industrial conditions courtesy of Pratt & Whitney WSK PZL-Rzeszów in Poland. An axial-symmetric drawpiece was chosen - a cone that acts as a cover in the jet engine chamber. The press machine and diagrams of the analyzed hydromechanical forming of cone methods are shown in **Figure 1**.

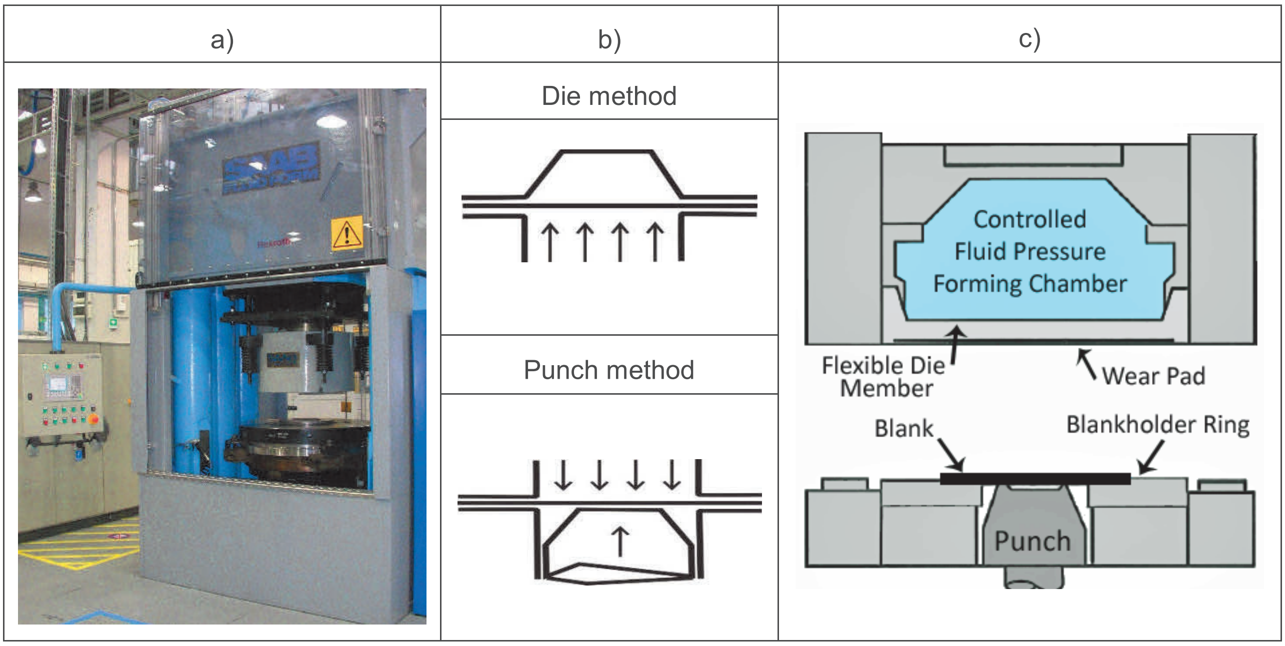

Figure 1 Hydromechanical froming process: a) press machine at Pratt & Whitney WSK PZL-Rzeszów, b) types of forming cone methods [own study]; c) diagram of tool set during hydroforming process [3]

2.2. Charge material and finished product

The light alloys representing by selected nickel, aluminum and magnesium alloys are mainly used in aviation and automotive on special functionality elements [4, 5]. For this reason, Inconel 625 nickel superalloy was chosen. From thin sheets of Inconel 625 nickel superalloy cone drawpieces were hydroformed. Forming process carried out in industrial conditions. The drawpieces were mechanically divided into main cross-sections (**Figure 2b**).

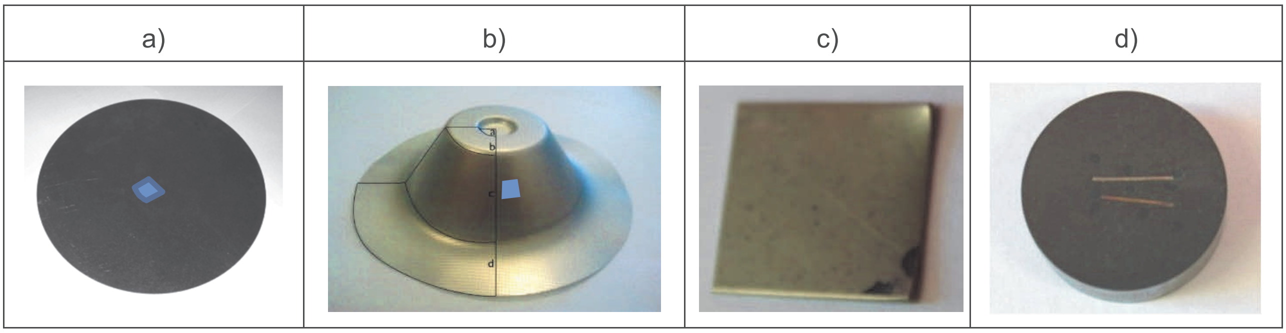

Figure 2 Inconel 625 alloy photographs: a) the charge for cone stamping - undeformed sample; b) cone drawpiece with signed line of cross-section cutting - deformed sample; c) cut sample; d) included sample for microstructure analysis

The distributions of local strains, levels of deformation and distribution of alloy components on these surfaces of cone and cross-sections were analyzed. Quantitative analysis of plastic flow characteristics of the Inconel 625 sheet metals 0.45 mm thick in this process was made using a portable measurement system AutoGrid. The charges for cones were 215 mm dimension discs with 2 mm square mesh subdivision (**Figure 2a**). For the analysis of the structure of the incoming sheet blank and the drawpiece after deformation, the samples from the charge and the drawpieces were cut in the selected areas in **Figure 2a** and **2b**. The photograph of the taken sample is shown in **Figure 2c** and the samples that were included for the microstructure study - in **Figure 2d**.

3. ANALYSIS OF LOCAL STRAIN DISTRIBUTION ON CONE DRAWPIECE

Cone drawpieces were made using machin, tools and metod schowed at **Figure 1**. While numerical simulations of this manufacturing process were done using Eta /DYNAFORM software commercial version 5.9. The procedures of forming limit curve of Inconel 625 alloy preparation and obtaining material model characteristic describe in earliest work [6, 7]. The comparison of simulated and measured values of local strain distribution is given in **Table 1**. In addition, the corresponding measurements and simulations of the main strain values distributions for the cone drawpiece are shown in the **Figure 3** nad **Figure 4**.

Table 1 Local strain distribution simulated and measured on industrial cone drawpiece [own study]

Part of Drawpiece	**Major strain (-)**		**Minor strain (-)**	
	Simulation	**Mesurement**	**Simulation**	**Measurement**
Pressing in the bottom	1.120	0.470	-	-
Bottom	0.255	0.380	0.253	0.248
Side	0.178 -0.033	0.430-0.360	0.168 -0.061	0.190-0.071
Transition to the flange	-	-	0.08	0.03

Verification of the simulation was carried out, and the results of the comparison of local deformations of the measured and simulated strains with respect to the forming limit curve were presented in publications [6, 7]. Thanks to this comparison, the most effective method of creating the selected cone extrusion was selected - the stamp method. The product made with this method was subjected to analysis of chemical composition and microstructure.

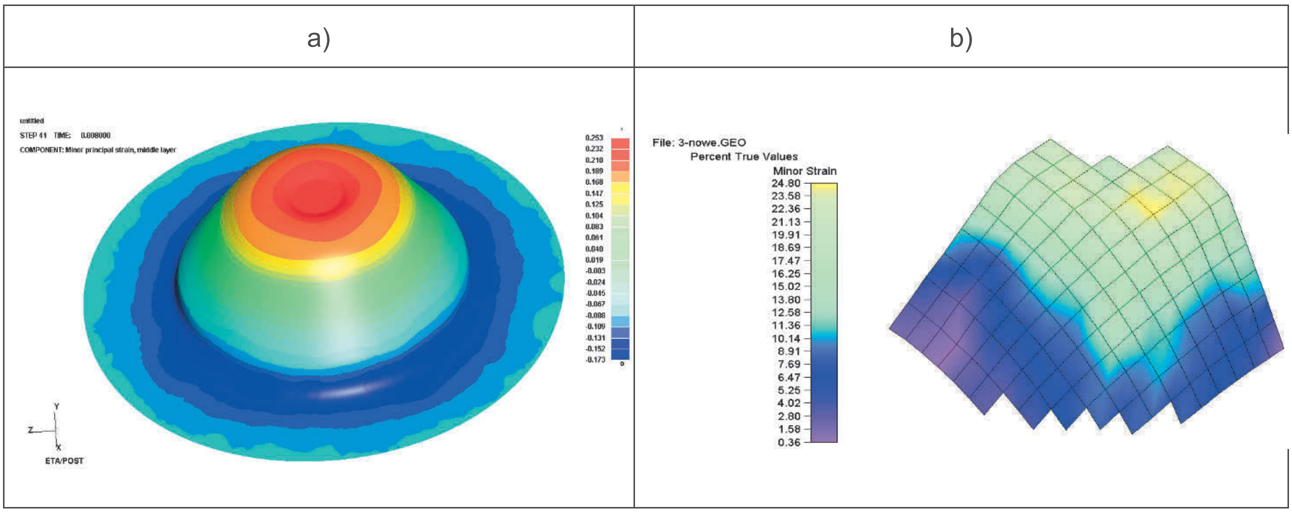

Figure 3 Hydromechanical forming process: a) simulation result; b) measurement of local minor strain distribution result on cone drawpiece

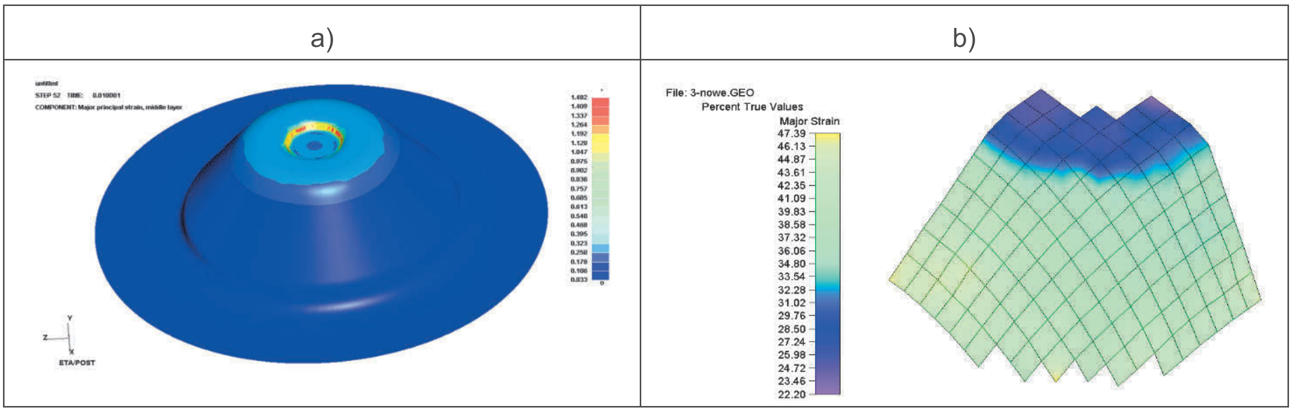

Figure 4 Hydromechanical forming process: a) simulation result; b) measurement of local major strain distribution result on cone drawpiece

4. ANALYSIS OF CHEMICAL COMPOSITION

The X-ray diffraction was used ty study the structure and chemical composition of Inconel alloy. Two types of samples were tested: undeformed sample (it came from charge sheet blank as show **Figure 2a**) and deformed sample (it came from cone as shown **Figure 2b** and has about 40% strain). The comparison of the resulting diffraction patterns was completed in **Figure 5**.

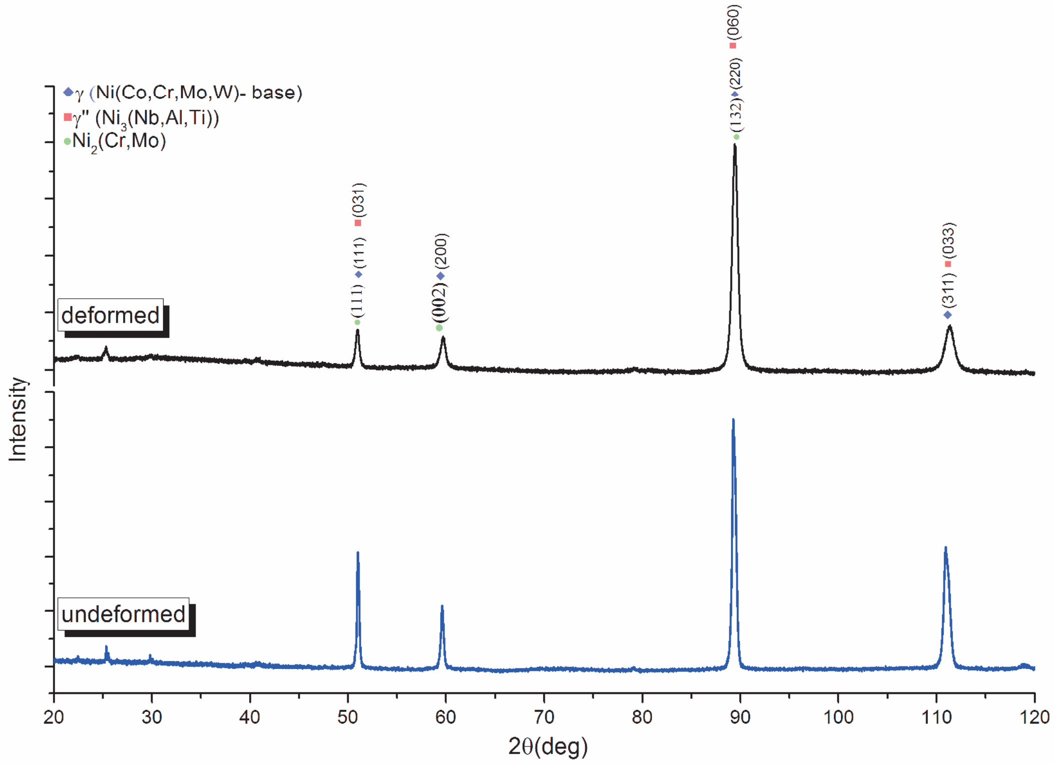

Figure 5 Comparison of the resulting diffraction patterns of undeformed and deformed (40% strain) samples of Inconel 625 alloy

Presented on **Figure 5** results were obtain at University of Silesia in Katowice, August Chełkowski Institute of Physics using Empyrean, Malvern Panalytical set of multipurpose diffractometer. Empyrean has the unique ability to measure all sample types - from powders to thin films, from nanomaterials to solid objects - on a single instrument.

5. ANALYSIS OF MICROSTRUCTURE

Metallographic examinations were carried out using the OLYMPUS GX51 metallographic light microscope with a computerized digital documentation stand based on the DD-12 camera supported by the AnalySIS image analysis program. The structure was observed using bright field techniques at 100x magnification. Comparison of metallographic longitudinal cross-section microstructure of undeformed and deformed (40 % strain) sample of Inconel 625 alloy shows **Figure 6**.

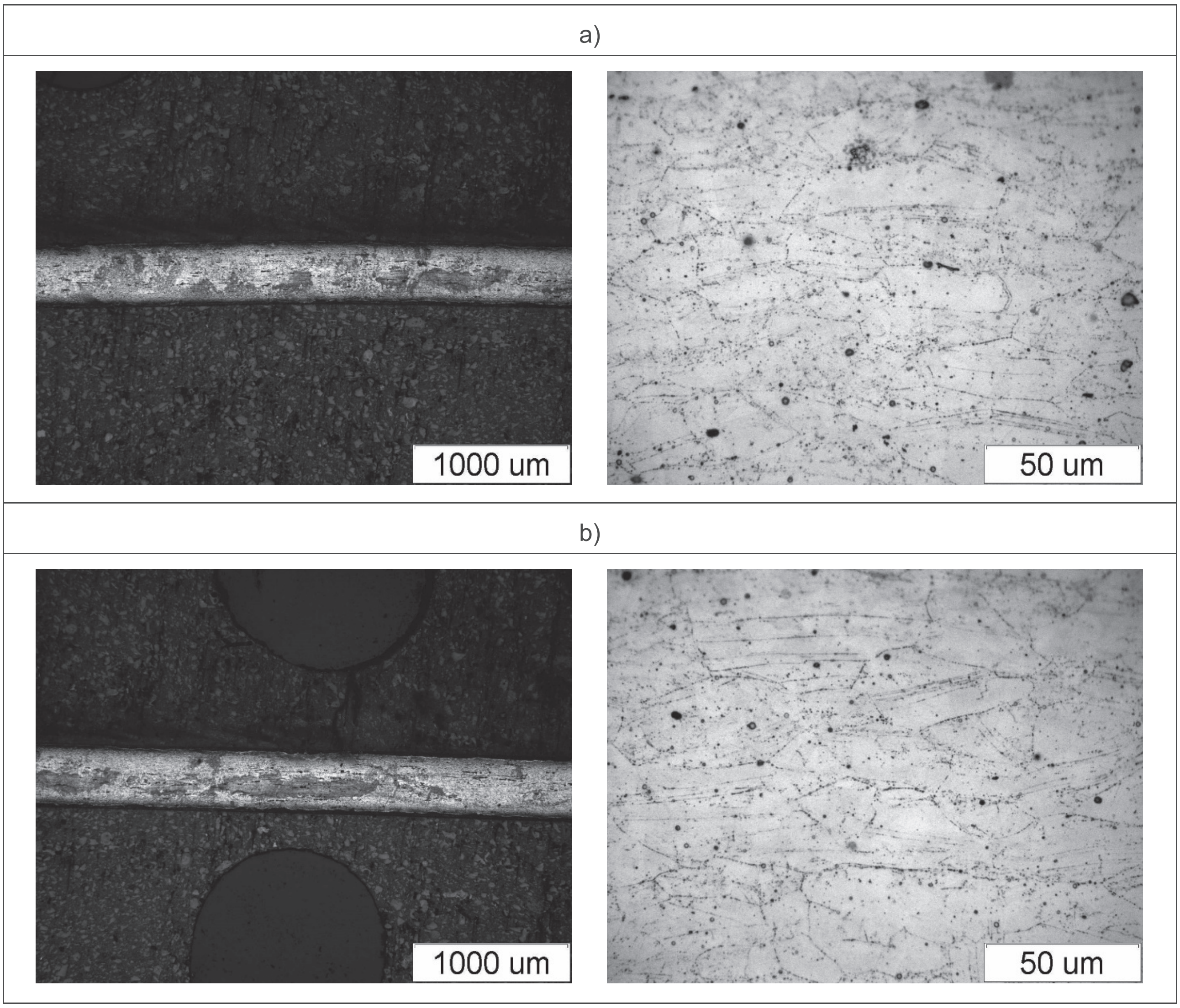

Figure 6 Microstructure of metallographic longitudinal cross-section of a) undeformed sample; b) deformed (40% strain) sample of Inconel 625 alloy

6. CONCLUSIONS

It has been shown that plastic deformation executed by method of liquid forming or hydroforming through elastomeric membranes allows preserving the original structure of Inconel 625 alloy sheet blank. Its change is not observed at the 100X magnification level.

After deformation, no new phase appears and the proportion of phases with crystallographic directions (132), (220) and (060) increases. This happens at the expense of reducing the share of the remaining phases that are recorded on the sample from undeformed sheet metal. Images of the alloy structure before and after deformation do not allow showing the influence of deformation.

The distributions of local deformations were analyzed and the maximal level of deformation value was determined at 40% strain. The distributions of local strain simulated and measured using strain analyzer AutoGrid are comparable only qualitatively. Quantitative differences are shown in the **Table 1**.

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