DOI: 10.24425/amm.2019.131117

M. HYRCZA-MICHALSKA[1*]

PHYSICAL AND NUMERICAL MODELING OF THE MANUFACTURING PROCESS OF A COMPLEX SHAPE PRESSED ELEMENT FROM A NICKEL SUPERALLOY

Products of complex geometry, aerodynamic shape and high quality surface finishes are among the most difficult to produce by using stamping methods. When additionally materials with special properties are intended, the task of determining their technological character becomes difficult to solve without the use of physical and numerical methods of process modeling. The paper presents the results of modeling the process of producing a single tube of the jet engine tubular diffuser subassembly. This is a product representative of such a complex geometry one. The charge material for this element requires resistance to operating conditions at elevated temperature and high durability. Therefore, an Inconel type nickel superalloy was proposed for the charge material. In the solution of designing the method of producing a single diffuser tube task, the capabilities of the AutoGrid automatic strain analyzer and the FEM simulation software Eta / Dynaform 5.9 were combined. Numerical simulations of different variants of the manufacturing process of the diffuser tube were made using the Eta / Dynaform 5.9 software. The results of forming simulations became the basis for the alternative technological cycle design of this drawpiece.

Keywords: complex geometry drawpiece, nickel superalloys, drawability, hydroforming, numerical modelling FEM

1. Introduction

In the aviation industry, the demand for products with complex geometry, aerodynamic shapes and high quality of surface finish is high. Products of this type are manufactured by pressing methods from thin sheets. All welded connections must be machined mechanically. In addition, charge materials with special properties are used for shaping: light, heat-resistant and heat-resistant, high-strength. Due to industrial secrecy and protection of companies' know-how, no detailed information is published about the methods of designing and manufacturing elements stamped from nickel superalloys. We only find general guidelines and qualitative descriptions of the results [1-3]. A novelty in the presented work is the numerical simulation of the process of hydromechanical forming tubular charge from nickel superalloy based on a material model extended with experimentally developed FLC. Also, the production of a complex drawpiece shape like the diffuser drawpiece shown has not yet been considered. Hence, the task of determining their technological properties becomes difficult to solve without the use of physical and numerical methods of process modeling. The search for the most optimal production method that meets rigorous standards for aircraft constructions is extremely difficult. The aim of the work was to develop an alternative technology for the production of a complex pressed element instead of the one used so far. As a model element, a tube (shown in Fig. 1b) of the tubular diffuser (shown in Fig. 1a) was selected. Initial results of drawability and simulation tests were collected in [4-10]. The AutoGrid system of allowed determining forming limit curve (FLC) of Inconel 718 alloy and implemented it to the material model in the FEM simulation of the modeled forming process. The material model in the FEM simulation was also supplemented by determined experimentally mechanical and technological properties.

2. Inconel 718 nickel superalloy

Selected nickel superalloy is Inconel 718. This is an alloy that exhibits several key characteristics: excellent mechanical strength (up to 820 MPa), resistance to thermal creep deformation (up to 700°C), good surface stability and resistance to corrosion or oxidation. The crystal structure is typically face-centered cubic austenitic. Inconel's are precipitation-hardenable nickel-chromium alloys, containing large amount of iron, niobium

1 SILESIAN UNIVERSITY OF TECHNOLOGY, FACULTY OF MATERIALS ENGINEERING, 8 KRASIŃSKIEGO STR., 40-019 KATOWICE, POLAND

* Corresponding author: monika.hyrcza-michalska@polsl.pl

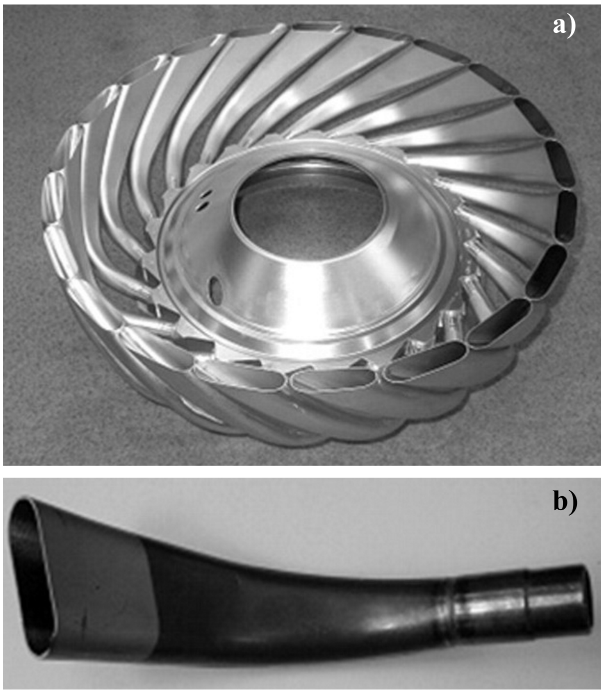

Fig. 1. Pictures of the tubular jet engine diffuser subassembly: a) the whole subassembly, b) a single tube

and molybdenum. They also contain small amounts of titanium and aluminum. Chemical composition of studied Inconel alloy is shown in table 1, whereas mechanical properties in table 2.

TABLE 1

Chemical composition of studied Inconel alloys

Alloy	Element content, % mas						
	Ni	Fe	Cr	Si	Mo	Mn	C
Inconel 718	50.0-55.0	Bala-nced	17.0-21.0	0.35	2.80-3.30	0.35	0.08

TABLE 2

Measured mechanical properties of selected nickel superalloys

Alloy	Thickness [mm]	UTS [MPa]	YS [MPa]	A_{50} [%]
Inconel 718 sheet	0.9	1276	1034	15
Inconel 718 seamless tube Ø45 mm	0.9	1172	1000	15

To define dawability of Inconel 718 alloy forming limit curves (FLC) was determined. In these tests a spherical punch of 75 mm diameter and a set of samples (discs and undercuts discs different width) were used. A modern AutoGrid local strain analyzer and a method of image analysis of the deformed parting grids with mesh parameter of 1 mm diameter have been used for quantitative evaluation of drawability of Inconel alloy sheets. More details of Inconel alloys sheet metals forming limit curves determination are presented in previous publications [4,9,11,12]. FLC of Inconel 718 was implemented into material model of numerical simulation in Eta / Dynaform 5.9 software [13].

3. Design manufacturing process of industrial drawpiece

The analysis of the current single tube of tubular jet engine diffuser production technology has been made at Pratt & Whitney Rzeszów S.A. Poland, which is representative of press shop of aircraft industry. Actually each tube is made of two or more parts joined (see Fig. 2). Each single part of tube is cold drawing using rigid tools. Here is a large technological allowance for stamping sheet. It should be reduce to make process more economically effective. Inconel 718 alloy 0.9 mm thick is used as a charge material. Its drawability is average or limited, for improving the plastic flow, lubricants for cold stamping are used. For these reasons, the modification or change of manufacturing technology is an expected innovation. The new manufacturing method proposals will be developed using numerical simulation.

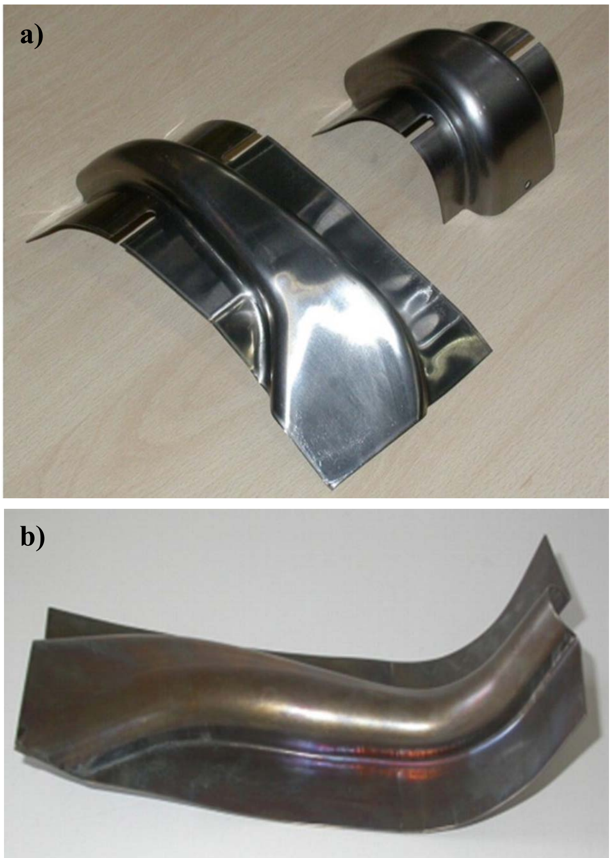

Fig. 2. Pictures of part of a tubular drawpiece of tubular diffuser subassembly: a) part bending after drawing, b) deep drawn part

4. Numerical simulation of tube drawpiece manufacturing

The industrial data of forming tubular drawpiece were transferred to Eta / Dynaform 5.9 software for the relevant preparation of actual manufacturing process model using FEM [1,2,14-19], especially to check accuracy of prepared material model. According to [20,21] springback analysis was conducted for Inconel sheet blank, to prepare tubular blank using roll forming manufacturing method and laser welding to join it. Afterwards modeled and simulated were innovative manufacturing processes of tubular drawpiece. It was first hydroforming of tubular blank. The idea of tube hydroforming reduces numbers of pressed elements and friction by using elastic tools and working liquid. Next, a conical tube with laser seam became the charge material as the result of the need to create a twisted tube line that discharges the exhaust. This solution achieved the best innovation and was widely tested. Representative results of simulation of laser welded conical tube hydroforming consists Figure 3.

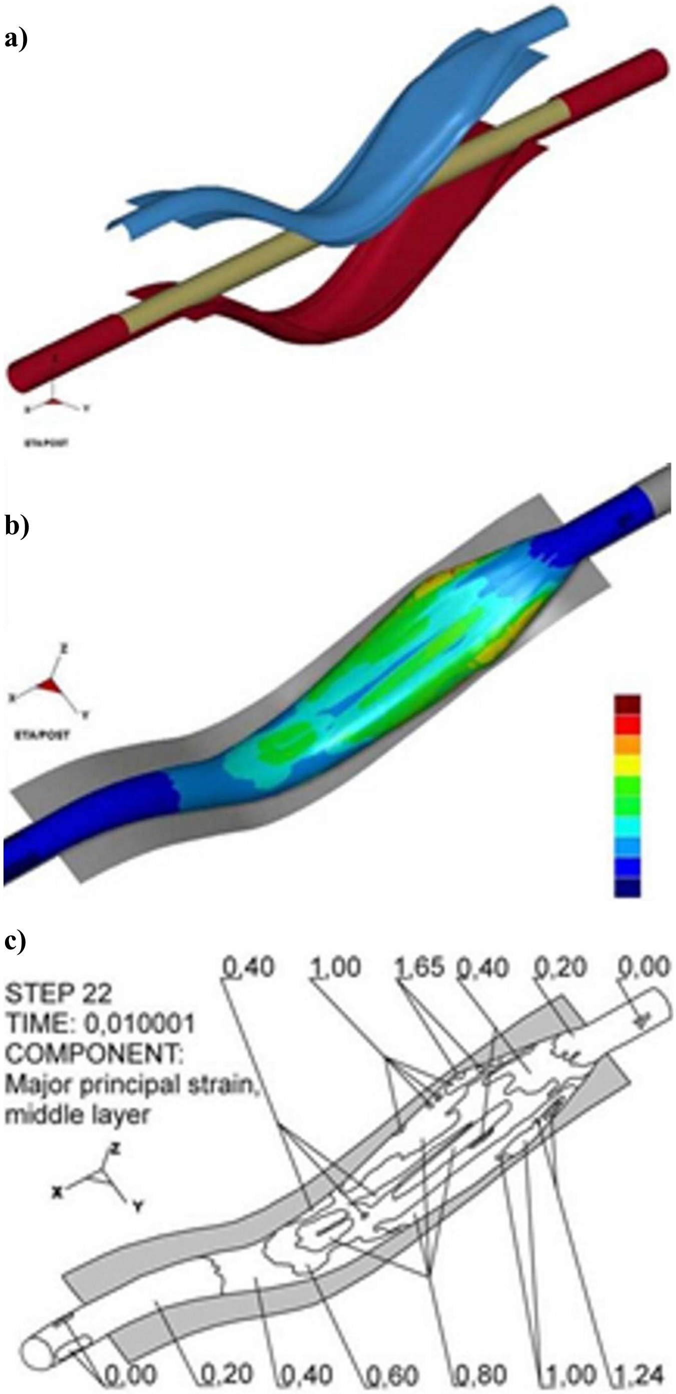

Fig. 3. The modeling results of the conical tube liquid forming using Eta/Dynaform software: a) tolls set and charge material, b) view element after forming with color scale of local strain – qualitative analysis, c) quantitative analysis of local major strain distribution [4]

Optimal solution brings implementation of available in software material model No. 36 * MAT_3-PARAMETER_BARLAT [13], data and material characteristics Inconel alloys from uniaxial tensile tests, drawability tests and forming limit curves achieved experimentally. Shown in Fig. 3b the values ε_1 of local strains for the analyzed variant of manufacturing the diffuser tube from a tubular charge exceed the allowable values ε_1 for Inconel 718 described by FLC. For this reason, this variant has not yet been subjected to industrial tests and the search for an alternative manufacturing method continues.

It has been shown that the methodical use of physical and numerical modeling brings effective benefits in the process of selecting the method of manufacturing stamped products using alternative solutions, such as the use of working liquid instead of rigid stamping tools [22-24]. The optimal form of the charge was determined. The limiting phenomena of the selected nickel superalloys forming were defined. In addition, the drawability of the charge material was assessed qualitatively and quantitatively. A measurable profit was obtained in the form of shortening the time of designing the technological cycle by reducing the variants of manufacturing methods for practical verification. Only the best solution is planned to be verified in industrial conditions.

5. Summary and conclusions

The presented procedure for designing manufacturing operations is of a universal nature. It supports the designer's work for the complex shape of pressed products.

By using the software for modeling and numerical simulation, e.g. Eta/Dynaform, it can be less time-consuming and effort-saving way to develop how to produce the tubular drawpiece. It was demonstrated that hydromechanical forming allows getting the products of a complex geometry, high strength like from Inconel 718 alloy and good surface quality.

The best solution of forming tubular drawpiece from laser welded conical tube is hydroforming. For a more favorable local strain distribution, work on this solution will continue to be modified and improved towards simultaneous pressing of two sigmoid tubes.

Acknowledgements

This work was supported by Polish Ministry for Science and Higher Education under internal grant BK-205/RM0/2019 for Institute of Materials Engineering, Faculty of Materials Engineering and Metallurgy, Silesian University of Technology, Poland.

REFERENCES

[1] K. Żaba, M. Nowosielski, S. Puchlerska, M. Kwiatkowski, P. Kita, M. Głodzik, K. Korfanty, D. Pociecha, T. Pieja, Arch. Metall. Mater. **60** (4), 2637-2644 (2015).

[2] K. Żaba, W. Muzykiewicz, S. Nowak, Arch. Civ. Mech. Eng. **8** (3), 153-154 (2008).
[3] E. Kaya, B.Akyüz, Open Eng. **7** (1), 330-342 (2017).
[4] M. Hyrcza-Michalska, Steel Res. Internat. Spec. edit. 2010 Metal Forming Conf. **81** (9), 817-820 (2010).
[5] M. Hyrcza-Michalska, Hutnik **77** (8), 394-397 (2010).
[6] M. Hyrcza-Michalska, P. Płonka, T. Mrugała, in: K. Świątkowski, J. Dańko, M. Pietrzyk, L. Blacha, J. Dutkiewicz, J. Kaźor (Eds.) Polska Metalurgia w latach 2006-2010, Komitet Metalurgii Polskiej Akademii Nauk, Kraków 2010.
[7] M. Hyrcza-Michalska, Oficyna Wydawnicza Politechniki Warszawskiej, Prace Naukowe, Mechanika **238**, 51-58 (2011).
[8] M. Hyrcza-Michalska, Steel Res. Internat. Spec. edit. 2012, 14th International Conference Metal Forming, **83** (9), 663-666 (2012).
[9] M. Hyrcza-Michalska, Sol. St. Phenom. **212**, 259-262 (2014).
[10] Final Report of Polish National Development Project N R15 0042 06, Development of methods for computer-aided design process of stamping products for the aerospace industry, 2013 Silesian University of Technology, Katowice, (unpublished materials).
[11] M. Hyrcza-Michalska, Sol. St. Phenom. **246**, 75-78 (2016).
[12] M. Hyrcza-Michalska, Hutnik **79** (8), 595-599 (2012).
[13] Eta/DYNAFORM Application Manual, 2007 Engineering Technology Associates, Inc., Troy.
[14] P. Lacki, J. Adamus, W. Więckowski, J. Winowiecka, Arch. Metall. Mater. **58** (1), 139-143 (2013).
[15] J. Lisok, A. Piela, Arch. Civ. Mech. Eng. **4** (3), 33-44 (2004).
[16] Z. Marciniak, Mechanika procesów tłoczenia blach, 1961 Państwowe Wydawnictwa Naukowo-Techniczne, Warszawa.
[17] J. Rojek, J. Jovicevic, E. Oñate, J. Mater. Process. Tech. **60** (1-4), 243-247 (1996).
[18] W.P. Romanowski, Tłoczenie na zimno: Poradnik, 1962 Wydawnictwa Naukowo-Techniczne, Warszawa.
[19] O.C. Zienkiewicz, The Finite Element Method in Engineering Science, 1971 McGraw-Hill, London.
[20] S.A. Asgari, M. Pereira, B.F. Rolfe, M. Dingle, P.D. Hodgson, J. Mater. Process. **203** (1-3), 129-136 (2008).
[21] M. Hojny, Arch. Metall. Mater. **55** (3), 713-723 (2010).
[22] M. Hyrcza-Michalska, Hutnik **82** (8), 542-545 (2015).
[23] M. Hyrcza-Michalska, Hutnik **78** (8), 625-628 (2011).
[24] M. Hyrcza-Michalska, Hutnik **85** (8), 264-266 (2018).