FORMABILITY ANALYSIS OF RUBBER PAD-BASED FORMING PROCESS OF DRAWPIECES

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Abstract

In this article, the results of modifications of the forming process of the bearing housing of a turbine engine are presented. The bearing housing is one of the critical structural elements of a turbine engine and is made of AMS 5504 stainless steel. Due to the nature of the element operation, the permissible shape error of housing profile is 0.508 mm. The proposed modification of the element forming process consists of welding two coupled parts into one and the calibration of the profile. This process is replaced by two steps expanding the cone-shaped drawpiece with the use of the rubber pad forming process in a SAAB hydro-mechanical press. Eliminating one weld allows us to reduce the manufacturing costs of parts and also to improve the strength of the part. To optimise the expanding process of the cone-shaped drawpiece, the finite-element-based IMPETUS Afea system was used. Measurements of shape errors of the drawpiece were carried out using the GOM ATOS Core instrument, which is optimised for the 3D measurement of small- to medium-sized components.

Keywords: Finite element method, rubber-pad forming, stainless steel, turbine engine

1. INTRODUCTION

Stainless steel is an iron-based alloy, which contains various combinations of other elements to give it characteristics suitable for a wide range of applications, especially in the aerospace industry. The most commonly used corrosion and heat-resistant AMS alloys are used for bushings, fasteners steam/gas turbine blades and buckets, nuclear reactor control rod mechanisms, and valve components. Stainless steels contain chromium to form a passive film of chromium oxide, which prevents surface corrosion by blocking oxygen diffusion to the steel surface. A thin and hard adherent oxide film protects the base metal from corrosion. The high content of martensite due to the accumulated strain in the multistage processes increases the working force and decreases corrosion-resistivity [1]. Therefore, annealing processes are necessary during and after multistage deep drawing processes [2].

Proper conduct of the sheet metal forming process requires knowledge of friction behaviour in the tool-workpiece interface, e.g. contact pressure, sliding velocity, sheet metal surface roughness, tool surface roughness, tool material and lubricant conditions, and temperature [3]. In metal forming and metal working operations, material transfer may result in built-up layers or the formation of lumps of adhered work material on the tool surface, especially when the workpiece is made of stainless steel [4]. As Nosar et al. found [5], despite a very low surface topography (Ra < 20 nm), a fine polished tool steel surface cannot prevent initial transfer of stainless steel to the tool steel surface.

Stainless steel sheets can be formed with an application of metal forming methods. In the forming, seizure tends to occur because microwelds happen at the interface between the tool and workpiece when this protective film is broken. In ironing, oil as a lubricant is generally required to prevent seizure [6]. In deep drawing, the tendency of seizure occurrence is increased because of excessive plastic deformation. Azushima et al. [7] fund that it is generally desirable for the workpiece surface to be rougher than the tools or die, as a means of the retaining lubricant at the interface. Except for lubricant usage, the other method to prevent seizure is application of rubber pad forming [8]. The forming process with use of flexible tools has many advantages: mainly tool profitability and production flexibility [8]. Techniques using advanced sheet-forming processes of stainless steel are still being developed and investigated [5, 9-11].

The formability of stainless steel sheets can be greatly improved by heat treating before cold working or by the use of hot-forming methods. The behaviour and formability of sheet steel in the forming processes have been the subject of a few studies. Stachowicz et al. [9] concluded that the optimal temperature of warm deformation of AMS5504 stainless steel is the temperature in the range of 500 °C. Material deformed at this temperature is characterised by the highest value of uni-form elongation, which assures satisfactory sheet metal deformation. The causes of the formation of wrinkles on the basis of the metal flow obtained from the results of a computer simulation of stamping process were studied by Woźniak et al. [7]. Adamus et al. [10] presented a method for determining forming limit curves based on a combination of experiments with finite element analysis. The development of new parts through forming by single operation or several progressive operations required good information of the attainable forming limits [12, 13].

In this paper, the results of experimental and numerical investigations of the forming process of the turbine engine bearing housing made of AMS 5504 stainless steel are presented. The proposed modification of the element forming process consists of welding two coupled parts into one and the calibration of the profile. This process is replaced by two steps expanding of the cone-shaped drawpiece with the use of the rubber pad forming process in a SAAB hydro-mechanical press.

2. MATERIAL

The turbine engine bearing housing is made of AMS 5504 stainless steel sheet with nominal thickness of 1.00 mm. Type AMS 5504 is a basic hardenable martensitic stainless steel and is well suited for use in highly stressed parts, where properties such as corrosion resistance, good strength and ductility are required. The chemical composition of the tested sheet is presented in **Table 1**. A tensile test in the universal testing machine was carried out to determine the mechanical properties. Those determined in this test are yield stress σ_y, ultimate strength σ_u, elongation A_{80}, anisotropy coefficient *r*, strain hardening coefficient *C* and strain hardening exponent n. The samples for the tensile tests were cut in three directions: along the rolling direction (0°), transverse to the rolling direction (90°), and at an angle of 45° with respect to the rolling direction. Three samples were tested for all directions and the average values of the parameters are presented in **Table 2**. The elastic parameter values, e.g. Young's modulus *E* and Poisson's ratio *v* are equal to 210 GPa and 0.3, respectively. The density of the tested sheet is 7800 kg / m^3.

Table 1 Chemical composition of AMS 5504 stainless steel sheet (wt. %)

Element	C	Cr	Ni	Mn	Si	P	S
Content	0.08-0.15	11.5-13.5	0.75	1.00	1.00	0.040	0.030

Table 2 Mechanical properties of AMS 5504 stainless steel sheet

Sample orientation	σ_y (MPa)	σ_u MPa	A_{80} (%)	R (-)	C (MPa)	N (-)
0°	340	557	26	0.435	0.244	998
45°	356	566	27	0.430	0.257	1045
90°	357	567	30	0.607	0.247	1024

3. EXPERIMENTS

The results of modifications of the sheet forming process of the bearing housing of the turbine engine are presented. The bearing housing is one of the critical structural elements of such an engine. Due to the nature of the element operation, the permissible shape error of a housing profile is 0.508 mm. The proposed modification of the element forming process consists of welding the two coupled parts into one, and the calibration of the profile. The drawing of the intermediate conical shape (**Figure 1a**) to a final shape (**Figure 1b**) takes place in a special device (**Figure 2**) mounted on the SAAB hydro-mechanical press. When the membrane is in contact with the blank, the chamber of the device is closed by the pressure pad. Further upward movement of the press creates a pressure that starts the sheet metal forming process. This pressure is dependent on the force of resistance, and can be adjusted during the process [8].

(a) (b)

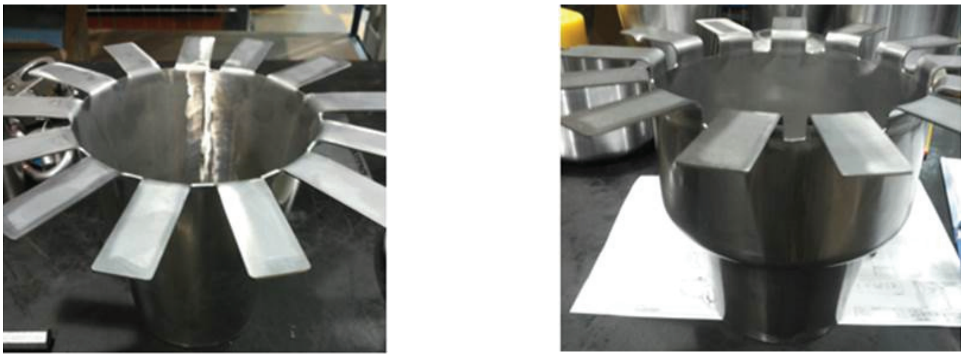

Figure 1 Conical half-finished element prepared for drawing (a) and the element after first expanding (b)

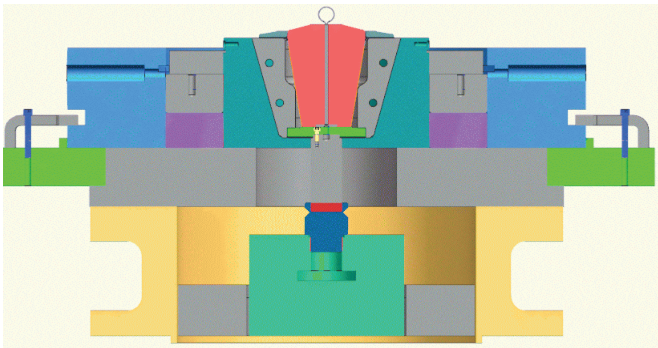

Figure 2 Cross-section of the device to form the bearing housing on the SAAB press

Due to the difficult geometry (i.e. the difficult shape to form, e.g. a large difference in diameters, low value of shape errors and the permissible thinning), the designer of the detail has allowed for the manufacturing of this element from two half-pieces. The welding of the two half-pieces requires the complex process of manufacturing of such an element: two dies (for both halves of the bearing housing), a dedicated device for automatic TIG welding, and a calibrator. In addition, such a manufacturing process requires a large number of technological operations (including more heat treatments).

4. NUMERICAL MODELING

To optimise the expanding process of the cone-shape drawpiece, the finite element method, based on the Impetus Afea program, was used. Numerical models of the drawpieces before and after the first forming stage, and details of the numerical model, are shown in **Figure 3**. The rubber pad consists of two stable elements and a third one that is placed loosely on the blank. The oil pressure on the upper surface of the rubber diaphragms was applied. The polyurethane pad was placed between rubber diaphragms and the sheet metal.

The two-parameter Mooney-Rivlin model is used to model the rubber parts. The Mooney-Rivlin material constants for the investigated rubber pads are determined based on experimental stress-strain curves: C_{10} = 3.9 x 10^6 and C_{01} = 0.1 x 10^6. The initial Young's modulus $E_0 = 6(C_{10} + C_{01})$ and the bulk modulus K_0 are equal to 24 x 10^6 Pa and 4.7 x 10^9 Pa, respectively. The mechanical properties of the blank material were taken from experimental data (**Table 2**).

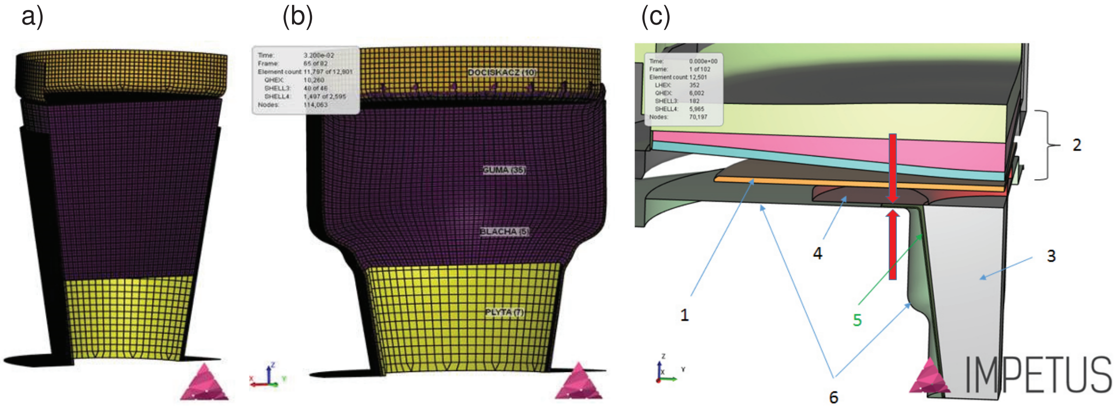

Figure 3 Numerical models of: drawpiece for expanding (a), the final element (b) and details of the numerical model (c): 1 - elastic pad, 2 - elastic rubber diaphragms of SAAB press, 3 - elastic punch, 4 - binder, 5 - sheet metal, 6 - die

5. RESULTS AND DISCUSSION

In the initial stage of the forming process, the conical blank shape (**Figure 1a**) after plate bending has been welded longitudinally using the TIG technique, and then was heat treated to eliminate the stresses arising during the plate bending operation. The operation of rolling and polishing of the weld, which has allowed us to achieve high dimensional accuracy of the profile in the area of face of weld, has also been introduced. This process is replaced by two steps expanding of the cone-shaped drawpiece with the use of the rubber pad forming process in the SAAB hydro-mechanical press. Eliminating one weld allows us to reduce the manufacturing costs of parts and also to improve the strength of the part. The element of the bearing housing was welded to the mounting rings (to be treated in the CNC machine), due to the permissible conditions of setting of the elements connected to each other for welding (resulting from the welding standards for the aerospace industry). The manufacturing standards require strengthening of tolerance of both the larger and smaller diameters of the bearing housing. Thanks to the expanding operation, we eliminated the operation of extending the bearing housing diameters before the welding process. Deviations of both the diameters are within suitable tolerance: 0.15 mm.

The verification of the shape error was carried out using the ATOS Core System, which is optimal for the 3D measurements of small- to medium-sized objects. For scanning the ATOS Core device has a projector which projects fringe patterns using a special narrowband blue led light and two cameras which record the fringe patterns projected on the object. Reference points were applied to the object in such spots that they could be captured from two sides of the object to capture the whole object. A scan was performed using the rotating table scanning 360 degrees from eight different angles. When the scan of the stamped part was completed the deviations between the registered shape of the drawpiece and CAD parameters of the ideal drawpiece were estimated.

The element was formed using the die method on the SAAB hydro-mechanical press. Due to the complex shape of the part, and the usage of the cold-working process, it was necessary to introduce additional technological ears (**Figure 1**). This was due to the fact that during expansion, the conical-shaped element has been indented into the die. During this process, the ripples of the sheet were formed or the area of the upper part of the bearing housing was too small. However, the use of expansion was associated with a very careful selection of process parameters, the sequence of drawing, and determination of the appropriate technological allowances.

Due to the large deformation of the material, the expanding process was divided into two stages:

- the first expansion of the upper part of housing without interfering with the lower part of the housing; in this step, in the lower part of the housing, a metal insert has been placed,
- the second expansion using a rubber profile insert, and sizing of the lower diameter of the element (**Figure 4a**).

After the second expansion, the element is stress-relief annealed, and then is re-calibrated using a rubber insert.

a) b)

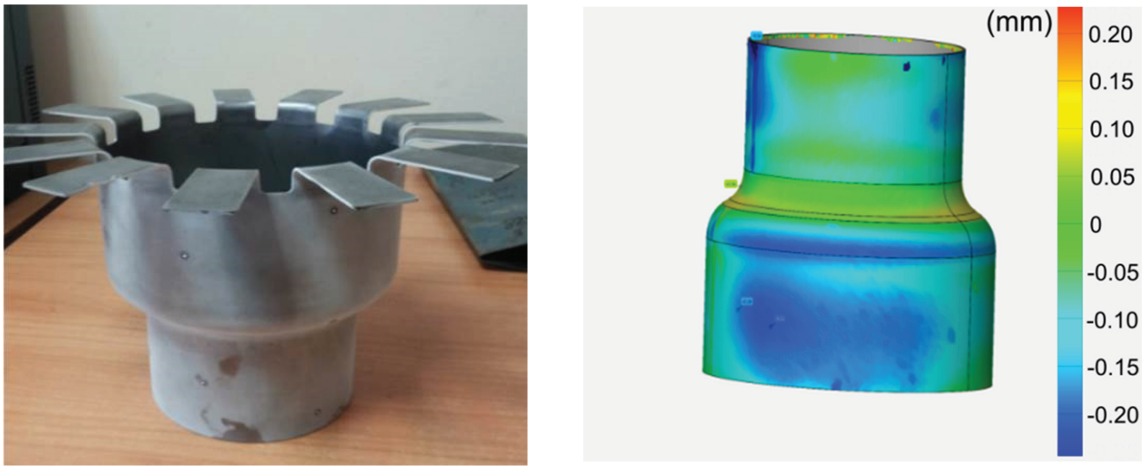

Figure 4 View of the finished drawpiece (a) and the distribution of the shape error (b) obtained using the GOM ATOS Core instrument

Both the analysis of the distribution of the shape error (**Figure 4b**) obtained by the system GOM ATOS Core instrument and the analysis of the numerical results of the sheet thickness distribution (**Figure 5**) along a generatrix of the housing showed that the permissible dimensional deviations of the element were never exceeded. Thickness analysis has shown that its computed distribution is in agreement with the results of industrial tests. The deviation values for the flange are not taken into account, because these areas are cut off in trimming operations and are treated as waste.

a) b)

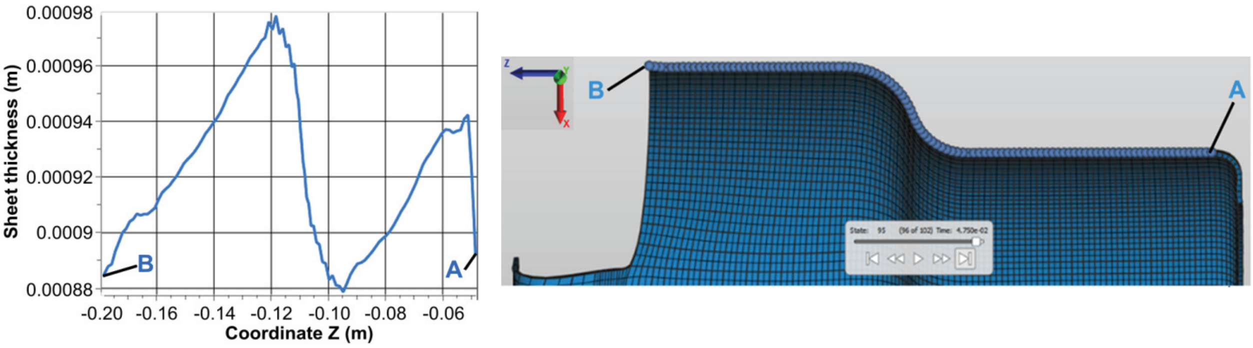

Figure 5 Distribution of sheet thickness (a) along a generatrix of bearing housing (b)

6. CONCLUSIONS

In this article, the successful modification of the sheet metal forming process of bearing housing of a turbine engine has been presented. The element was made of stainless steel, which is very hard to form in cold forming conditions. The forming process is replaced by two steps expanding of the cone-shaped drawpiece with the use of the rubber pad forming process in a SAAB hydro-mechanical press. Eliminating one weld allows us to reduce the manufacturing costs of parts, and to also improve the strength of the part.
The analyses of geometric changes in the thickness of the sheet and changes of the shape showed that permissible values were not exceeded. The application of expansion with the rubber tool eliminated the metallic contact between the tool-sheet interface. Therefore, negative seizing of the sheet surface was not observed, through the lack of the metallic contact between the metal sheet and swaging tools, flaring through the use of a rubber insert, eliminating blurring of the sheet surface.

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