TWO-STAGE RUBBER-PAD BASED FORMING OF FAN ENGINE BEARING HOUSING

MALINOWSKI Tomasz[1], PIEJA Tomasz[1], TRZEPIECINSKI Tomasz[2], ZABA Krzysztof[3]

[1] Pratt & Whitney Rzeszów, Rzeszów, Poland, EU
[2] Rzeszow University of Technology, Faculty of Mechanical Engineering and Aeronautics, Rzeszów, Poland, EU
[3] AGH University of Science and Technology, Faculty of Non-ferrous Metals, Cracow, Poland, EU

Abstract

In this paper, the forming process of the bearing housing element of a fan engine is investigated. Because the bearing housing is subjected to corrosion and a heat-resistant environment, this part is made of AMS5604 stainless steel. Due to the specific mechanical properties of the AMS5604 alloy, that is, a high ratio of yield stress to ultimate tensile strength, the forming process must be realized under special conditions. To achieve a suitable shape and dimensional accuracy of the final part, the forming process is divided into two stages. Firstly, a rubber-pad forming process is applied. Next, the part heated to the temperature of 830 ºC is calibrated in a grease-lubricated stamping die. The distribution of the drawpiece shape error is obtained by the system GOM ATOS Core. The results of SEM metallographic evaluation and analysis of the chemical composition by using energy dispersive X-ray spectrometry are also presented.

Keywords: AMS5604, fan engine, rubber-pad forming, springback, stainless steel, warm forming

1. INTRODUCTION

The continuous development of new technologies, market competition, or strive for continuous improvement of product quality to seek solutions to support decision-making processes at the stage of pre-production. At the moment, it is difficult to imagine the functioning of a modern industrial plant, where at the design or production stage, the benefits of modern design and decision-making systems can be overlooked. The aerospace industry is characterized by a very large complexity of manufacturing processes, starting with the classic stamping processes using rigid tools, through unconventional forming processes such as for example, forming using rotary tools [1] and finally, to the design of welding processes components necessary for the production of aircraft engines [2]. The springback phenomenon is one of the key problems in determining the quality of drawpieces, in particular in forming titanium alloys and high-strength steels, including stainless steels. The change in the shape of the formed elements is a result of the relaxation of internal stresses after unloading [3]. The phenomenon of changes in the geometry of drawpieces with complex geometry is also the result of the non-homogeneous state of strain in a cross-section of bent sheet metal [4], which depends on the mechanical properties of the bent material; the geometric parameters of the bending process, that is, the angle and radius of bending, the width and thickness of the sheet, and the ratio of width to thickness of the material; and the technological parameters of forming such as the strain rate and temperature, the yield strength of the sheet material, the tendency to strain hardening, the frictional phenomena, and the material microstructure [5-7]. Forming temperature is one of the basic parameters in materials processing technologies. Heating reduces the resistance to deformation, ensuring appropriate deformability of the material [8].

In this paper, the forming process of the bearing housing of a fan engine is investigated. The formed element is made of stainless steel AMS5604, which is hard to form in cold conditions. To achieve a suitable shape and dimensional accuracy of the final part, the forming process is divided into two stages: rubber-pad based forming and calibration at warm temperature.

2. MATERIAL

The fan engine bearing housing is made of hardenable martensitic AMS5604 stainless steel sheet with a nominal thickness of 1.00 mm. The chemical composition of the tested sheet is presented in **Table 1.** A tensile test was carried out according to EN ISO 6892-1:2009 [9] on a universal testing machine to determine the mechanical properties. The properties determined in this test are the yield stress σ_y, ultimate tensile strength σ_u, elongation A_{80}, and anisotropy coefficient r. The strain hardening coefficient C and strain hardening exponent n are determined based on the approximation of true stress. Stress-strain relation using the Hollomon function, $\sigma_y = C\varphi^n$, where φ is the true strain. 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, namely the Young's modulus E and the Poisson's ratio v, are equal to 210 GPa and 0.3, respectively.

Table 1 Chemical composition of AMS5604 stainless steel sheet (wt. %)

C	Cr	Ni	Mn	Si	Mo	Nb
0.07	16.5	4.0	1.0	1.0	0.5	0.3

Table 2 Mechanical properties of AMS5604 stainless steel sheet

Sample orientation	σ_u (MPa)	σ_u (MPa)	A_r (-)	r (-)	C (MPa)	n (-)
0°	898	1145	0.047	0.76	3794	0.405
45°	930	1058	0.045	0.93	3633	0.402
90°	893	1021	0.035	0.95	3158	0.343

3. METHOD

The aim of the investigations was to develop the technology for the manufacture of a fan engine bearing housing element (**Figure 1**) in order to ensure that the obtained part has a certain shape and dimensional accuracy. The bearing housing is one of the critical structural elements of an engine and the permissible shape error of a housing profile is ± 0.25 mm. As the forming material, a sheet rolled into a cone shape is used. Before the forming process, the sheet metal is welded using the TIG (Tungsten Inert Gas) welding technique without the use of additional material. The weld is tested using Fluorescent Penetrant Inspection (FPI) and radiography (X-ray) to detect the following defects: shrinkage cracks, inclusions, gas pores, surface defects, leaks, and lack of fusion. Because of the tight dimensional tolerances of the formed tools and possibility of their damage during forming, the weld is rolled with a tolerance of protrusion of 0.1 mm. Metallographic evaluation by SEM (Scanning Electron Microscopy) and analysis of the chemical composition by Energy Dispersive X-ray Spectrometry (EDS) were also carried out.

Figure 1 The fan engine bearing housing element

4. RESULTS AND DISCUSSION

Considering that formed material exhibits a low tendency to plastic deformation (a high value of the ratio of yield stress to ultimate tensile strength) and a high value of springback, it was decided to divide the forming process into two stages:

- forming of the blank using a rubber punch (**Figure 2**);
- calibration of the drawpiece after heating the material to a suitable temperature.

Realizing the forming process with the use of flexible tools, that is, rubber-pad based ones, offers many advantages such as production flexibility and tool profitability. Flexible tools make it possible to obtain a variety of final product shapes, which can be very complicated. The main attraction of rubber forming is its simplicity.

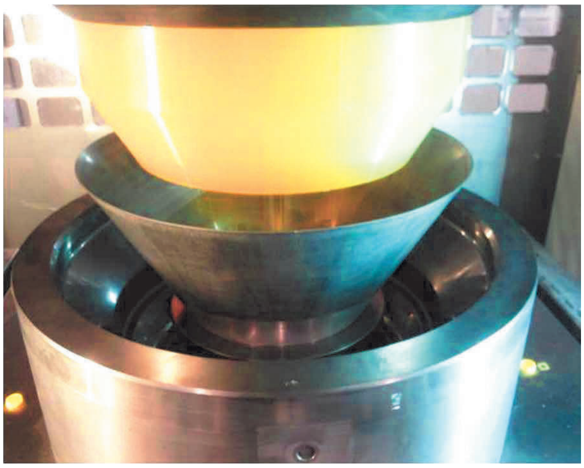

Figure 2 Rubber punch

Drawing of the intermediate conical shape (**Figure 2**) takes place in a special device mounted on a 160 MN triple-action hydraulic press with independent movement of the punch, die, and pressure pad. When the elastomeric punch 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. In the calibration process, the elastomeric punch is replaced by the metallic punch. The metallic dies are made of hardened Unimax® steel, hardened three-times and their working surfaces are covered by PVD (Physical Vapour Deposition) coating.

After the first stage of forming, the profile of the drawpiece consists of a cylindrical part, which causes blocking of the drawpiece in the die. Thus, the die is equipped with a shedder of finished parts. It is possible to minimize the springback by changing the selected process parameters and dimensional and shape correction of the punch and die [10]. The idea of correction of tools depends on forcing additional overbending of the sheet. Two stiffeners (**Figure 3**) are used at an angle of -5° with respect to the profile of the drawpiece in order to ensure the formation of the rounded portions of the profile. Prediction of the final shape is essential for designing tools. Moreover, to secure the lower part of the cone-shaped blank against wrinkling, the holder is applied to the upper surface of the flange of the drawpiece (**Figure 4**).

Taking into account the abovementioned problems in the forming of AMS5604 stainless steel sheet, we decided to apply calibration of the drawpiece at elevated temperature. A preformed cone (**Figure 4**) was heated in a radiation-resistant chamber furnace. The drawpiece was heated to a temperature of 830 °C. Heating was carried out without a protective gas atmosphere. The process caused surface oxidation, but this is acceptable considering the operation of the element. At the stage of moving the sheet from the furnace to the die, there is fast transfer of heat into the environment by convection and radiation. The sheet temperature at the start of the calibration process was about 560 °C.

Figure 3 The fan engine bearing housing element

Figure 4 The shape of the drawpiece after the first forming stage

After cutting off the auxiliary surfaces of the bearing housing were removed, and the element is welded to the steel rings using the TIG welding technique. According to the technical documentation, the permissible shape deviations in all sections should be within a tolerance of ± 0.25 mm from the nominal shape, while the deviation of the sheet thickness should be within the range of tolerance of ± 0.06 mm. The range of deviations concerns the final shape of the drawpiece, that is, after cutting off the technological allowance, which is necessary to obtain the correct shape of drawpiece. Due to the complex geometry of the bearing housing, the anisotropic properties of the AMS5604 material, and the strong springback phenomenon of the material, it is very difficult to obtain both the required profile and a uniformly distributed thinning of the sheet around the perimeter of the drawpiece. The analysis of the distribution of the shape error (**Figure 5**) obtained by the GOM ATOS Core instrument system showed that the permissible dimensional deviations of the element were not exceeded.

Visual examination of the drawpiece fragment showed the occurrence of stains on the surface (**Figure 6**). These changes have a superficial character. Furthermore, spalling is observed in areas of colour change (stains). Metallographic examination of the cross-sections revealed a uniform microstructure in the whole section except for local changes in oxidation on the surface. There were no significant differences in the microstructure between the evaluated samples in the areas beneath stains and without stains. The results of the chemical analysis of the drawpiece surface carried out by SEM EDS in the areas marked in **Figure 7** are presented in **Table 3**.

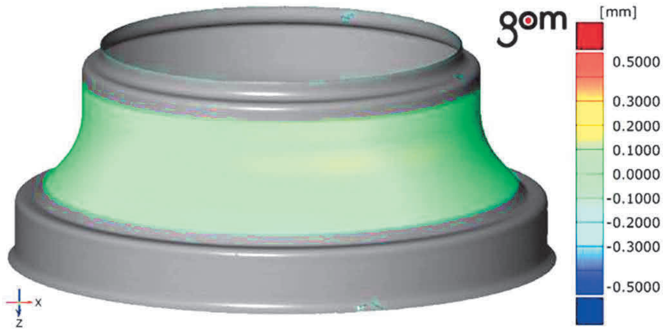

Figure 5 The distribution of the shape error obtained using the GOM ATOS Core instrument

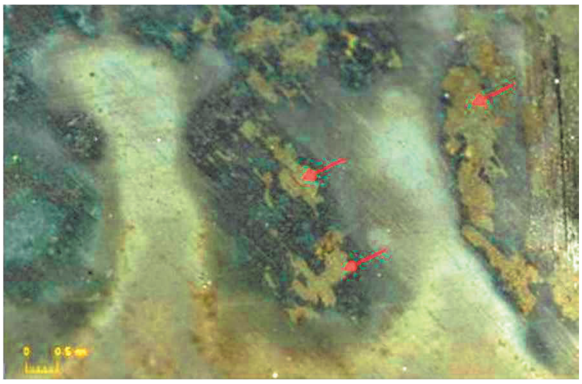

Figure 6 Stains on the drawpiece surface

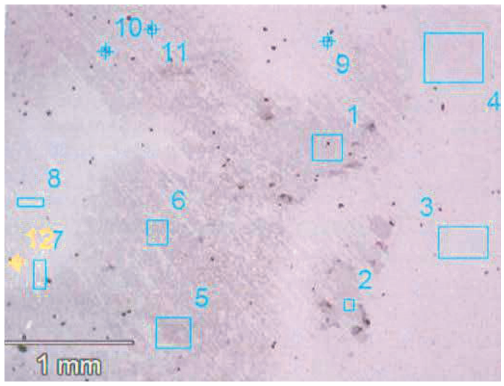

Figure 7 View of the surface of the drawpiece with marked areas where the SEM EDS analysis was carried out

Table 3 Chemical composition of selected areas of the sample (wt. %)

Point no.	*O-K*	*Si-K*	*Cr-K*	*Mn-K*	*Fe-K*	*Ni-K*	*Cu-K*	*Ag-L*
1	25.2	0.9	34.8	0.5	33.1	1.6	2.9	
2	24.1	0.9	33.9	0.5	35.5	1.3	2.9	
3	22.3	0.2	6.8	1.0	65.2		3.0	
4	21.7	0.5	15.8	1.0	56.0	0.7	3.0	
5	21.3	0.1	2.1	0.8	68.2		4.0	
6	21.0	0.1	2.3	0.8	68.2		4.2	
7	21.7	0.1	3.1	1.0	65.5		2.9	2.8
8	25.9	0.2	6.6	1.0	60.3		2.5	1.5
9	20.2	0.2	2.4	0.9	65.0		3.7	
10	26.0	0.1	5.5	1.0	62.1		2.9	
11	24.9	0.1	1.9	0.8	64.4		4.7	
12	26.7	0.1	3.6	0.8	57.7		2.7	6.7

The whole surface is covered with oxides. In the sample areas the Ag particles (points 7, 8, and 12) were observed. The highest difference in element content is found for Cr. Two types of oxides exist on the sample surface: the first type, with a higher amount of Cr, covers the whole surface of the sample (and also the areas without stains), and the second type, which contained mainly iron, is visible only in areas of colour change.

5. CONCLUSIONS

In this paper, the rubber-pad forming and warm calibration process stages are applied to form a fan engine bearing housing. Based on the experimental results, the following conclusions can be drawn:

- The application of the rubber-pad based tool eliminated the fractures in drawpieces;
- The calibration of the final shape of the drawpiece allowed elimination of material shrinkage at elevated temperature, so both the shape and dimensions of the drawpiece are within the permissible values;
- Application of stiffening of the upper and lower parts of the bearing housing at a negative angle with respect to the generatrix of the drawpiece made it possible to avoid wrinkling of the material;
- The distribution of the shape error obtained by the optical 3D measuring GOM ATOS Core device showed that the permissible dimensional deviations of the element were not exceeded;
- Two types of oxides exist on the sample surface: the first type, with a higher amount of Cr, covers the whole surface of the sample, while the second type, which contains mainly iron, is visible only in the areas of colour change.

REFERENCES

[1] Bewlaya, R. et al. Net-shape manufacturing of aircraft engine disks by roll forming and hot die forging. *Journal of Materials Processing Technology*, 2003, vol. 135, no.2-3, pp. 324-329.

[2] Hojny, M. Thermo-mechanical model of a TIG welding process for the aircraft industry. *Archives of Metallurgy and Materials,* 2013, vol. 58, no. 4, pp.1125-1130.

[3] TEKASLAN, Ö., GERGER, N., ŞEKER, U. Determination of spring-back of stainless steel sheet metal in "V" bending dies. *Materials & Design*, 2008, vol. 29, no. 5, pp. 1043-1050.

[4] RAGAI, I., LAZIM, D., NEMES, J. A. Anisotropy and springback in draw-bending of stainless steel 410: Experimental and numerical study. *Journal of Materials Processing Technology*, 2005, vol. 166, no. 1, pp. 116-127.

[5] LAURENT, H., GREZE, R., MANACH, P. Y., THUILLIER, S. Influence of constitutive model on springback prediction using the spring-ring test. *International Journal of Mechanical Sciences*, 2009, vol. 51, no. 3, pp. 233-245.

[6] BOLJANOVIC, V. *Sheet metal forming processes and die design*. 2nd Edition. South Norwalk: Industrial Press, 2014.

[7] TRZEPIECIŃSKI, T., LEMU, H.G. Frictional conditions of AA5251 aluminium alloy sheets using drawbead simulator tests and numerical methods. *Strojniski Vestnik - Journal of Mechanical Engineering*, vol. 60, no. 1, pp. 51-60.

[8] MA, J., YANG, H., LI, H., WANG, D., LI, G. Tribological behaviors between commercial pure titanium sheet and tools in warm forming. *Transactions of Nonferrous Metals Society of China*, 2015, vol. 25, no. 9, pp. 2924-2931.

[9] ISO standard no. 6892-1:2009. Metallic materials - Tensile testing - Part 1: Method of test at room temperature.

[10] FORCELLESE, A., FRATINI, L., GABRIELLI, F., MICARI, F. The evaluation of springback in 3D stamping and coining processes. *Journal of Materials Processing Technology*, 1998, vol. 80-81, pp. 108-112.

[11] KIM, H., KADES, N. *Friction and lubrication*. In: Sheet metal forming. Fundamentals, ALTAN, T., TEKKAYA, A. E. (Eds.) Materials Park: ASM International, 2012, pp. 89-104.

[12] RAMEZANI, M., RIPIN, Z. M. *Rubber-pad forming processes. Technology and applications*. Duxford: Woodhead Publishing, 2012.