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RESEARCH ON IMPACT FACTORS INFLUENCING ROUNDNESS OF PRODUCTS MADE OF AL 99.5% FORMED BY FLOW FORMING TECHNOLOGY

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Abstract: Cold forming is characterized by a number of advantages which are mainly result of material strengthening during the final workpiece formation. Effects of material strengthening are reflected in shaping accuracy and in improving mechanical characteristics of workpieces. Flow forming is one of the specific forming methods used to form different parts of rotationally symmetrical parts in military, aeronautical, nuclear and other industries, which uses positive effects of the material strengthening. Design of products for extremely demanding industries, in addition to dimensional control, requires checking the accuracy of their circular shape. This paper, through the example of making tubular workpieces from Al 99.5% using flow forming technology, presents a method for determining the workpiece roundness using a 3D Coordinate Measuring Machine and analyzes the influence of number of revolutions, shift and the deformation rate to the deviation of roundness.

Keywords: Al 99.5%, Forward Cold Flow Forming, Workpiece Roundness

1. INTRODUCTORY PART

The cold metal flow forming as a specific method of a rotary shaping enables, in addition to shaping the pieces of different dimensions, reduction of thickness of wall. Due to the reduction of thickness in the cold state, an effect of strengthening of material happens, which improves the mechanical characteristics.

In addition to enhancement of characteristics of strength of manufactured parts, it is pretty significant that this method can be used to model parts of satisfactory accuracy of shape and dimension. The reason for this research is a lack of practical recommendation and experience regarding the efficient shaping of parts of Aluminium of pureness 99,5% (technically pure aluminium) by use of forward cold flow forming method. Therefore, to study the factors which impact the accuracy of shape and dimensions of workpieces manufactured on the basis of flow forming method, the experimental researches were conducted on the pieces of technically pure aluminium Al 99,5.

2. TECHNOLOGY OF FORWARD COLD FLOW FORMING

The essence of cold flow forming (CFF) method as a rotary shaping method is to have the material, under the influence of pressure of rolls (two or three), transformed into the field of plastic flow and pushed in the axial direction while reducing the diameter and increasing the length of the workpiece. There are several methods of CFF tubular parts, and two main types of technology process of CFF are: forward or direct (FCFF) and indirect / in an opposite direction (ICFF). The variants mainly differ in the way the material flows considering the direction of moving the rolls, while the deformation of metals in both variants is localized to a narrow contact zone of contact tool-rolls and workpiece materials. Figure 1 is a schematic presentation of the principle of forming the subject variants HRIV with the working elements of tools.

In a direct CFF (Figure 1, left) flow of non-deformed material of workpiece / a preformed shape, the movement of rolls (tools) is in the same direction, and in an indirect CFF, which is in opposite direction, (Figure 1, right) flow of material is also in the opposite direction in regard to the direction of movement of rolls.

Since the purpose of this research primarily was to determine the possibility of using the FCFF technology on Al 99,5 to make a workpiece of satisfactory accuracy of shape and dimension with the adequate strength, it is necessary, in addition to controlling the dimensions of workpiece, to check the precision of its geometry by measuring roundness on 3D coordinate measuring machine.

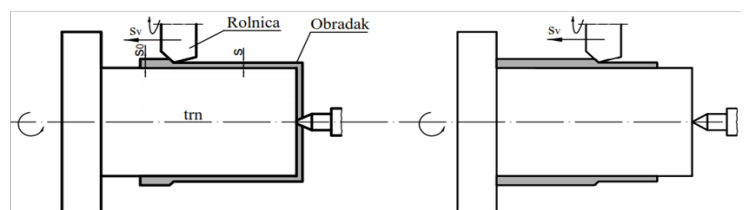


Figure 1. Scheme of procedure of direct (left) and oppositional (right) CFF [1]

3. ROUNDNESS OF WORKPIECE AND WAYS TO MEASURE IT

According to the definition, roundness refers to the state of circular line or surface of circular part, which all points on the line or on the circumference of the cross section are equidistant from a central point. Deviation from roundness is the radial width of the annular area between the two coplanar, mutually concentric circles. Since the 1950., when this term was introduced, the roundness was defined as an important characteristic of process, which enhanced the quality of defining the round-shaped parts. In the course of time, devices for measuring and control have been further developed. It is well known that today in specifications of equipment, needed for technical control and measurements in big, and also in small production organizations, due to many advantages, the coordinate measuring machines are the most applied. They execute many different measurements, but, also, provide possibility to measure roundness using the modern methods. These are methods of examining roundness with the external measuring reference (type of rotating tabel and type of rotating antenna), in contrary to the conventional method with the internal measuring reference (diametrical examining of roundness, examining of roundness by using the measuring spikes and examining of roundness by using the V-prism). For measuring roundness, as other devices, the coordinate measuring devices detect small deviations from an ideal shape of circle ("out of-round"), and today are used four recognizable methods to assess deviations from roundness: Method of the smallest circular squares, Method of the smallest circular zone, Method of the smallest circumscribed circle and Method of the biggest inscribed circle. Results of measuring roundness by these methods in average differentiate 10-15% [4].

4. EXPERIMENTAL WORK

In order to determine accuracy of manufacturing the parts of technically pure Aluminum in the course of cold forming, shaping Al 99,5 chamber was done in two phases of FCFE technology. Figure 2 brings dimensions of preform and workpiece by phases of FCFE technology.

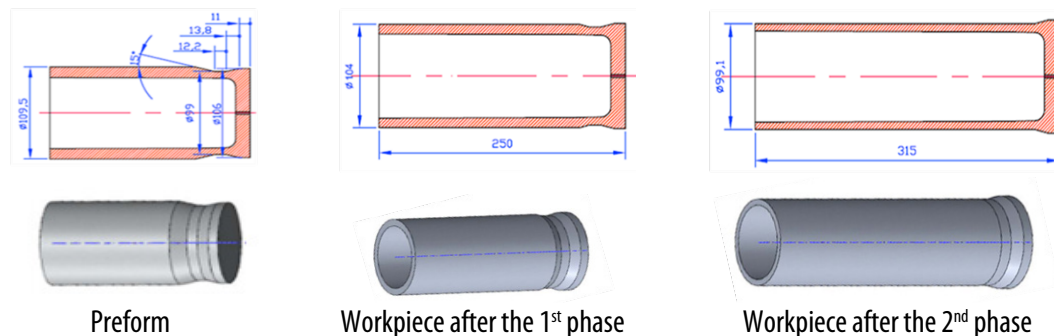


Figure 2. Desing and dimension of preform and workpiece in the 1st and 2nd phase of FCFE technology

4.1. Plan of experiment

For the experimental research, a total factor plan of experiment with three independent changeable factors ($k=3$) was used, and the experiment was repeated in the central point of the plan (zero plan point). Matrix plan and levels of variation of factors in the first and in the second phase are presented in the table of research results, Table 1.

Table 1. Comparative data on measuring roundness after the 1st and 2nd phase of FCFE technology

Run	Plan-matrix and natural factors levels in:						$\varnothing A$ [mm]	φ_{Σ} [%]	Parameters of roundness of workpieces after:			
	I-first stage			II-second stage					I-first stage		II-second stage	
	n [°/min]	s_v [mm/°]	Δs [mm]	n [°/min]	s_v [mm/°]	Δs [mm]			Roundness s [μm]	No. of Point	Roundness s [μm]	No. of Point
0	Preform						109,6		0,02577	1036	-	-
1	140	60	2	140	60	3,5	98,8	53,5	0,10912	998	0,16080	1836
2	240	60	2	240	60	3,5	98,8	53,4	0,17314	998	0,24337	1837
3	140	100	2	140	100	3,5	99,0	52,3	0,15110	1004	0,28626	1840
4	240	100	2	240	100	3,5	98,7	57,6	0,19841	999	0,15883	1836
5	140	60	3,5	140	60	2	99,0	51,7	0,20961	967	0,12755	1843
6	240	60	3,5	240	60	2	99,0	51,6	0,35027	966	0,12252	1840
7	140	100	3,5	140	100	2	99,2	50,7	0,20391	971	0,05995	1843
8	240	100	3,5	240	100	2	99,0	52,0	0,25744	969	0,06742	1847
9	190	80	2,75	190	80	2,75	-		0,14998	988	-	-
10	190	80	2,75	190	80	2,75	98,5	55,2	0,13363	988	0,08723	1842
11	190	80	2,75	190	80	2,75	98,8	53,2	0,10681	988	0,18138	1834
12	190	80	2,75	140	60	3,5	99,0	52,2	0,09001	984	0,18004	1836

where is: Rpm mandrel n [°/min]; Feed s_v [mm/°]; Depth of forming Δs [mm]; $\varnothing A$ Final outer diameter workpieces [mm]

On the basis of the experiment plan, there were 12 samples made by cold plastic forming by the FCFE procedure in two phases.

The achieved total degree of deformation during shaping is in the range from 50,7 to 57,6 %, and the partial degrees of deformation in specific phases are in the range of $\varphi_I=15,3$ do 35,4 % and $\varphi_{II}=16,3$ do 37 %.

The total percentage of obtained length in both cases, depending on the ordinal number of the sample, ranges from 35,5 % to 50,3 % (from $L_{\Sigma \text{extr.}}=74$ mm to 104 mm), and the total logarithmic degree of deformation by length ranges from $\varphi_{\text{Imin}}=0,27$ to $\varphi_{\text{Imax}}=0,59$.

The results of measuring roundness are presented in the following section.

4.2. Control of roundness on workpieces of Al 99,5 from the first and the second FCFF

The control of roundness on manufactured workpieces, in accordance to the planned experiment, including the preform for cold FCFF, was done on 3D coordinate measuring machine Zeiss Contura G2 in the Laboratory of measuring technics of the Faculty of mechanical engineering in Zenica.

The measuring probe with ball of radius $R=5$ mm was used, Figure 3.



Figure 3. 3D coordinate measuring machine, method of measuring with measuring probe for control of roundness

Deviation of roundness was detected by method of the smallest circular squares. Software for identification and processing of data Zeiss Calypso CNC Geometry of coordinate measuring machine writes this deviation value directly in the report on measuring.

4.3. Results of testing

Figure 4. brings the examples of the graphic presentations of deviation of roundness of particular workpieces after the second IHRIV phase and the summarized diagram of measuring results on all samples after the first and the second FCFF phase.

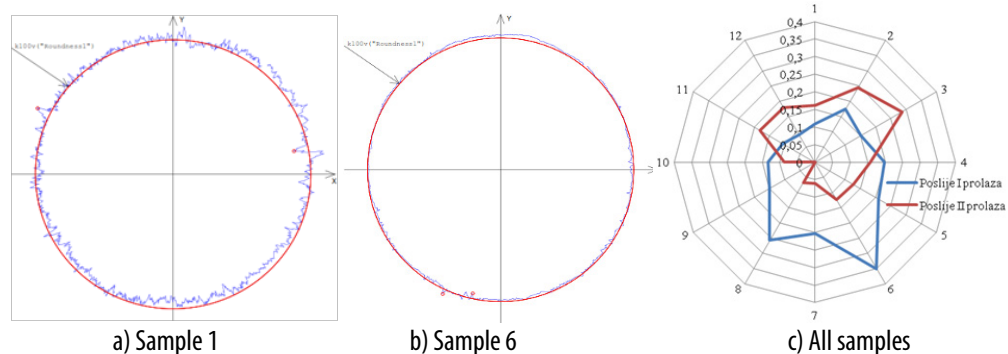


Figure 4. Example of graphic interpretation of deviation of roundness of sample from Al 99,5% after the second phase (a and b) and comparative results after the first and the second phase of FCFF technology on all samples (c)

A comparison of graphic presentations of all samples shows the smallest waste of deviation of roundness is after the second FCFF phase in samples done with the minimum and the medium values of processing parameters (n , sv , Δs), i.e. on samples 6, 7, 8 and 10, and the maximum deviation (cca $0,3 \mu\text{m}$) is on samples 2 and 3, made combining the maximum process parameters. The same conclusion can be made regarding the workpieces shaped in the first FCFF phase, and the figure 5 shows the graphic interpretation of deviation of roundness after the first and the second phase in function n , s and Δs .

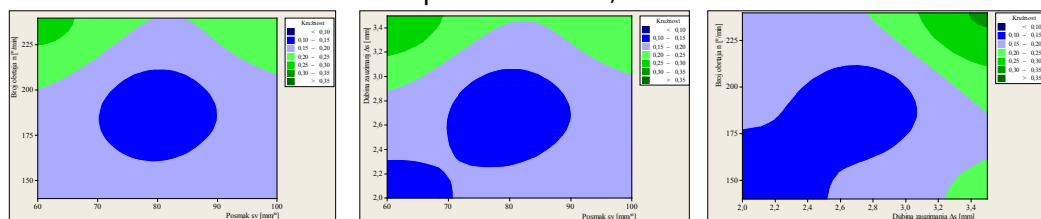


Figure 5. Diagram of deviation of roundness in function n , s and Δs

On the basis of these diagrams, it is possible to determine what are the optimum values of input parameters of shaping for achieving the minimum values of deviation of roundness in the final workpieces.

5. CONCLUSION

FCFF technology with the adequate geometrical characteristics of tools (diameter, radius, work angle, angle, radial and axial adjustment, etc.), technological (n and s) and other process parameters (pressure of rolls, agent for cooling and lubricating, etc.), and the achieved total degrees of deformation during shaping in the range from 51 to 58 % (partial degrees of deformation in the

particular phases in the range from $\varphi_I=15$ to 35 % and $\varphi_{II}=16$ to 37 %) efficiently can shape the axisymmetric workpieces of satisfactory accuracy of shape and dimension and with the improved strength characteristics comparing to the material of preform. On the presented diagrams, it can be seen that the smallest value of deviation of roundness for shaping Al 99,5 by FCFF procedure is in workpieces shaped by the medium values of the number of revolutions per minute (rpm) (170-200 r/min), feed rate (70-90 mm/o) and depth of forming-tool positioning (2-3 mm).

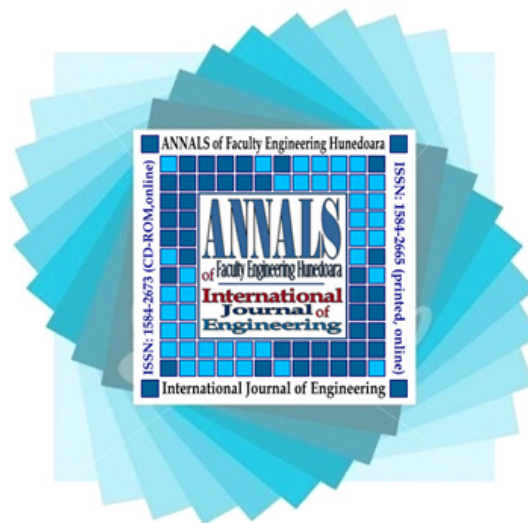
Data on deviation of roundness after the second phase of FCFF technology indicated that they were lower than in subject workpieces after the first phase. During both phases, depth tool positioning of rolls, had a little bit bigger impact on the roundness. If its value increases, deviation of roundness increases too. Therefore, to have more precise circular shapes of tubular workpieces, smaller degrees of depth of forming of rolls in shaping should be choosen.

The conducted regression analysis shows that a mathematical model of dependence of roundness on n , s and depth of tool positioning (Δs), i.e. the degree of deformation, can not be made with the sufficient reliability.

The comparison of the obtained data on measuring deviation of roundness of workpieces after the first and the second phase of FCFF technology leads to the conclusion that the mentioned procedure of processing (shaping) rotationally symmetrical workpieces of Al 99,5 can safely produce parts with the maximum deviation from an ideal circular shape in the range from 0,2 to 0,4 μm .

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