Journal of Chemical Technology and Metallurgy, 51, 6, 2016, 720-725

THE INFLUENCE OF ROLL SPRINGING ON THE PROCESS OF FORGE-ROLLING OF BILLETS IN CALIBERS

Igor M. Volodin, Pavel I. Zolotukhin, Evgenija P. Karpaytis, Aleksandr I. Volodin

Lipetsk State Technical University
30 Moskovskaya St., 398600 Lipetsk
Russian Federation
E-mail: zolotyhinpi1957@mail.ru

Received 26 May 2016
Accepted 09 September 2016

ABSTRACT

Regression equations are derived for the calculation of roll springing of ARWS-1, ARWS-1a, ARWS-2 and ARWS-2a forging rolls on the ground of experimental results referring to the production conditions effect and statistical data processing. They are included in a design technique focused on impressions of sector-dies for two-, three- and four passes hot forge-rolling.

Keywords: sector-dies, impressions, roll springing, statistic processing, regression equation, design.

INTRODUCTION

Billet forge-rolling is a rough operation in stamping forgings of a variable section on two-point hot-forging presses. The billet is deformed in rotating sector-dies located on a section of the circle of the forging rolls rollers. Forge-rolling makes it possible to produce semi-finished products which are rational in form and provide the minimum metal burrs at their subsequent hot die-forging [1 - 3, 8 - 11].

The dimensions of sector-dies impressions are determined on the basis of drawings of the forged billet operations. The depth of impression cutting H_b must be determined accounting for the roll springing ΔA (Fig. 1). The latter determines the increase of the center distance of the forging rolls A and, hence, the caliber height H_1. The value of springing depends on the mill's design and the deformation force P.

The caliber height H_1 must be less than the height of the corresponding section of the billet H_z by the value of springing ΔA, i.e.

$$H_1 = H_z - \Delta A \tag{1}$$

The dimensions H_1 and H_b are also related through:

$$H_1 = 2H_b + s \tag{2}$$

where S is the gap between the sector-dies. Therefore, the tool design has to take into account that the depth of impression cutting H_b has to be decreased by the value of $\Delta A/2$. The impression radius remains as calculated.

Deformation of the system of oval, round and square calibers is widely applied, when forge-rolling billets are used for further die-forging, Theoretical and experimental studies [1-3] show that the area of contact with the billet in case of forge-rolling in oval calibers and, hence, the force of deformation is greater than that at forge-rolling in round or square calibers. Therefore, it is enough, when designing sector-dies, to reduce only the height of the oval caliber by the value of springing ΔA to avoid lateral burring in the next deformed caliber. It is worth noting that the design height of the caliber is equal to the height of the billet in the section considered.

Forge-rolling is applied in the course of production of elongated forged parts [1 - 3, 9 - 11] in most of the enterprises in the field. The forge-rolled billets are die-forged there in open impressions laid flat wise. During die-forging the lateral burr formed during the last forge-rolling pass, when the metal exits the gap between rollers, can be trimmed (Fig. 2a).

New resource-saving technologies of die-forging circular forged parts from forge-rolled billets (Fig. 2b) are used for commercial production At PAO "KAMAZ-Metallurgiya" forge plant [4]. The forge-rolled billet is laid with its deformed part into a vertical forging impression. Lateral burr (if any exists) may lead to forged parts rejection. Increased quality requirements are imposed on the semi-finished product. The lack of lateral burr is one of the most important one. In fact billets with no burr can be obtained if springing while designing calibers is taken account of.

Due to a large number of factors influencing springing, the most reliable results are obtained experimentally for each mill model. A number of studies [1 - 3] are focused on the dependence of springing on the forge-rolling force for a number of open-end forging roll models. The aim of the present investigation is to derive empirical formulas (regression equations) determining the value of springing of rollers ΔA depending on the deformation force P for two-point ARWS-1, ARWS-1a, ARWS-2 and ARWS-2a forging rolls made by Eumucoas as there is no data available in the literature.

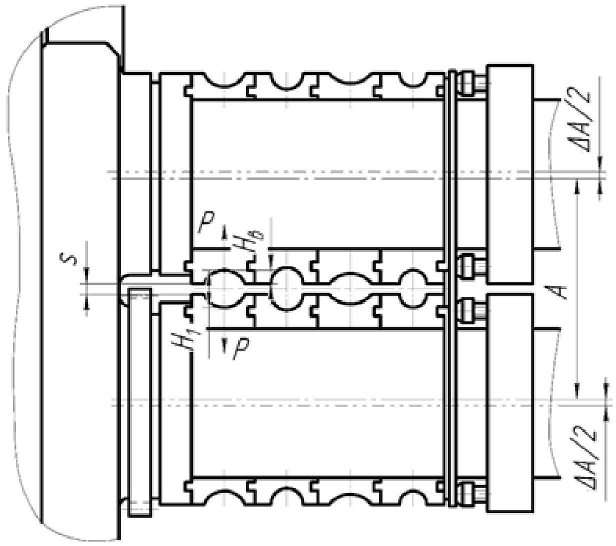

Fig. 1. Roll springing in hot forge-rolling of billets in calibers.

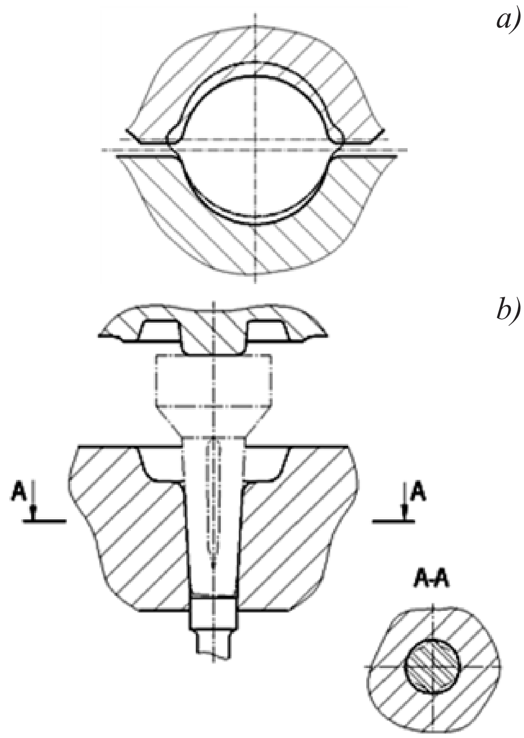

Fig. 2. Variants of laying a laterally burred forge-rolled billet: a – flat wise; b – vertically with subsequent up-end deformation.

EXPERIMENTAL

Formulas like $\Delta A = f(P)$ for each model of rolls were obtained by statistical processing of arrays of values of ΔA and P. Table 1 provides values of ΔA and P for rolling of billets on ARWS-2a rolls. The methods used refer to:

1. Forge-rolling technology design according to N.V. Smirnov [1]. It includes determination of the forge-rolling pattern, calculation of the cross-sectional and longitudinal dimensions of the billet and of the impressions of sector-dies by the pass, calculation of the effort and the torque by the pass. N.V. Smirnov's technique allows the estimation of the height of the billet's section H_z only. In order to determine the caliber height H_1 in correspondence with Eq. (1), it is necessary to have information on the value of springing ΔA for the applied forging roll model. The designers of the tool determine this value on the ground of their experience (or intuition) in absence of any a formula for its estimation.

2. Debugging of the tool after it was produced and the new technology was tested. If the value of springing ΔA determined by the designer is less than the required one, then the billet height H_z obtained in the course of a test forge-rolling is higher than the designed one. In this case a metal layer appears on the impressions surface while debugging the tool to decrease the caliber height H_1. At a large value of ΔA the height H_z obtained is less than the designed one and the lateral surface of the billet is burred. In this case, the impressions surface is grooved aiming to increase the caliber height H_1. Grooving or building-up of the surface of impressions may be repeated several times until the designed height of the billet H_z is obtained at test forge-rolling.

After that the value of springing ΔA is obtained as a difference between the height of the billet H_z and the height of the caliber H_1 determined during the tool debugging described above. Thus, the values of ΔA (see Table 1) are fixed under production conditions while debugging the tool in the course of test forge-rolling.

Table 1. Results of analyzing the production processes of hot forge-rolling of billets on ARWS-2a forging rolls.

Production process number	Forge-rolling pattern	Steel grade	Diameter of initial billet, mm	Pass number	Value of springing ΔA, mm	Force of forge-rolling P, kN
1	circle-oval-circle-oval	45X	120	1	2.0	2330
				3	1.9	1930
2	circle-oval-circle -oval-circle	20ХГНМТА	130	1	3.3	2990
				3	2.6	2720
3	circle-oval-circle -oval-circle	25ХГТ	110	1	2.3	1570
				3	1.8	1370
4	circle-oval-circle -oval-circle	20ХГНМТА	110	1	2.8	2990
				3	2.0	2730
5	circle-oval-circle -oval-square	35	90	1	1.9	1550
				3	2.6	2130
6	circle-oval-circle-oval-circle	20ХГНМТА	100	1	2.6	2050
				3	2.1	2160
7	circle-oval-circle -oval-square	40X	80	1	1.9	1690
				3	1.9	1360
8	circle-oval-circle -oval-square	40X	75	1	1.7	1720
				3	1.6	1080
9	circle-oval-circle -oval-square	40X	80	1	1.7	1880
				3	1.5	1100
10	circle-oval-circle -oval-circle	45X	100	1	2.4	1670
				3	2.4	1450
11	circle-oval-circle	20ХГНМТА	120	1	2.6	2970
12	circle-oval-circle -oval-circle	30Mn5	130	1	2.9	2760
				3	1.9	1160

The authors participated in the debugging of 16 new technologies of forge-rolling of billets on ARWS-2a forging rolls in two, three, and four passes according to the circle-oval-circle, circle-oval-circle-oval, circle-oval-circle-oval-circle, circle-oval-circle-oval-square patterns. Springing was determined during the first and the third passes (see Table 1). In both cases a round billet was deformed in the oval caliber.

3. Calculation of the force of forge-rolling P according to the method described in ref. [1]. The force P depends on the resistance of metal to deformation σ_s, the dimensions of the cross sections of the initial billet and the caliber, the rollers diameter, and the forge-rolling pattern. The values σ_s were determined in this study using the data from ref. [5] accounting for the grade of the deformed steel, the deformation degree and speed and the metal temperature in each pass. The designed values of P are given in Table 1.

Values of ΔA and P for other forging roll models were obtained in a similar way. The paper presents the analysis of 38 new technologies of forge-rolling of billets on ARWS-1, ARWS-1a, ARWS-2 and ARWS-2a forging rolls in two, three, and four passes according to the circle-oval-circle, circle-oval-circle-oval, circle-oval-circle-oval-circle, circle-oval-circle-oval-square patterns.

In order to obtain empirical formulas (regression equations) describing the dependence of springing $\Delta\grave{A}$ on the deformation force P, the obtained arrays $\Delta\grave{A}$ and P were statistically processed separately for each model of forging rolls.

All the stages of array processing [6, 7] are performed successively. They referred to an initial data test for their compliance with the law of normal distribution, a test for serious errors, calculation of the regression coefficients using the least squares method, assessment of the significance of the regression equation in general, as well as the significance of each coefficient, a test of the array of the residuals for compliance to the law of normal distribution. Data processing was carried out with the use of the Analysis ToolPack – an Excel add-in program [6]. The compliance of the empirical distribution of data in the arrays considered with the normal law was estimated on the ground of the indicator of asymmetry A_S and that of excess E_k. The elimination of the serious errors (emissions) in experimental selections (arrays ΔA or P) was performed according to N.V. Smirnov's technique.

After determining the coefficients in the regression equation the significance (adequacy) of this equation was estimated. The equation was considered significant in case the condition $\alpha_F < \alpha$ was met [6]. Here α (a = 0.05) is the set significance level (with confidential probability P = 0.95); α_F is the significance level corresponding to the designed F value for F-test proceeding. Further the significance of each coefficient of regression was tested. If the condition $\alpha_t < \alpha$ holds, then the coefficient of regression is considered significant [6, 7]. Here α_t is the level of significance corresponding to the designed t-value for t-test.

RESULTS AND DISCUSSION

Table 2 provides short technical characteristics of forging rolls and the ranges of changing of the technological parameters of the production processes investigated.

The calculations carried out show that the elements distribution in the initial arrays ΔA and P is close to the normal. There are no serious outliers in these arrays. The data distribution in the arrays of residuals is also close to the normal. Residuals refer to the difference between the value of the response function ΔA calculated in accordance with the regression equation and its initial experimental one. The regression coefficients found are most probable [6, 7] in case of normal distribution of the residuals.

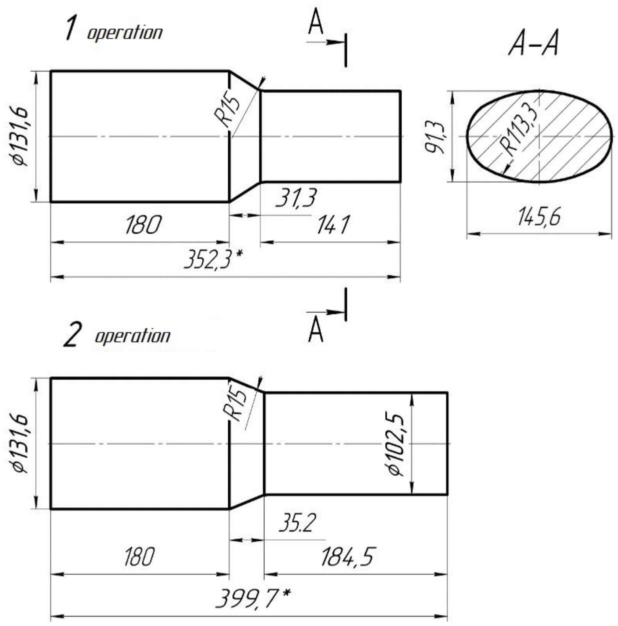

Fig. 3. Diagrams of two first operations of billet forge-rolling.

The following types of regression equations were obtained for the models of forging rolls researched:

ARWS-1 - $\Delta A = 2{,}37 \cdot \lg(P) - 4{,}92$ (3)

ARWS-2 - $\Delta A = 4{,}65 \cdot \lg(P) - 12{,}06$ (4)

ARWS-1a - $\Delta \mathrm{A} = 1{,}19 + 0{,}64 \cdot (P/1000)$ (5)

ARWS-2a - $\Delta A = 1{,}15 + 0{,}53 \cdot (P/1000)$ (6)

The intervals of changing of the basic statistical characteristics for the regression equations obtained are as follows: correlation rate r = 0,76…0,82; F-test calculated value F = 9,87 … 36,28; significance value α_F =2,0.10^{-6}…2,0.10^{-2}; significance value α_t =6,5.10^{-7} …2,3.10^{-2} (for regression coefficients). The characteristics given provide to deduce that all equations as a whole are significant ($\alpha_F < \alpha$) at α = 0.05 as each of the regression coefficients comprising the equations ($\alpha_t < \alpha$) is significant. Fig. 3 shows the diagrams of the first two operations of billet forge-rolling on ARWS-2a forging rolls in accordance with the circle-oval-circle-oval-circle pattern (the dimensions of the "hot" billet are shown). Fig. 4 presents

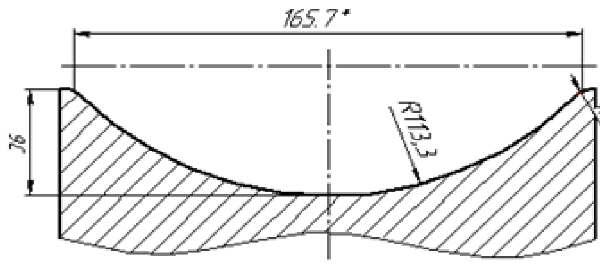

Fig. 4. 1st operation impression section.

Table 2. Short technical characteristics of forging rolls and the ranges of changing of the technological parameters.

№	Parameters	Roll model			
		ARWS-1	ARWS-1a	ARWS-2	ARWS-2a
1	Nominal center distance, mm	370	460	560	680
2	Nominal force of forge-rolling, kN	630	920	1250	3000
3	Sample size	10	8	19	29
4	Diameter of the initial billet, mm	50…60	50…70	70…95	65…130
5	Coefficient of elongation	1,23…1,45	1,24…1,65	1,16…1,55	1,16…1,53
6	Axial ratio of the oval billet	1,4…2,3	1,2…2,9	1,3…2,7	1,5…2,7
7	Springing ΔA, mm	0,9…2,0	1,4…1,9	1,5…2,7	1,3…3,3
8	Forge-rolling force P, kN	350…630	330…920	830…920	1080…3000

the cross-section of the 1st operation impression corresponding to section A-A of the forge-rolled billet. The value of springing $\Delta \grave{A}$ taken into account in designing sector-dies is equal to 3.3 mm. It is calculated in accordance with Eq. (6). The gap s between sectors is equal to 16 mm.

CONCLUSIONS

The investigation reported focused on the effect of roll springing on the process of forge-rolling of billets in calibers. Experimental results obtained under industrial conditions and statistical data processing were used. The design of impressions of sector-dies with account of roll springing calculated according to the formulas obtained in the paper excluded lateral burring on the billet at forge-rolling in the caliber following the oval caliber. The technique was applied to commercial production at the PAO "KAMAZ" forge plant.

REFERENCES

1. N.V. Smirnov, Hot roll-forming of parts, in V.K. Smirnov, K.I. Litvinov, S.V. Haritonin, Moscow, Mashinostroenie, 1980, (in Russian).
2. S.A. Skryabin, A.I. Kolpashnikov, Billet shaping on gorging rolls, Moscow, Mashinostroenie, 1988, (in Russian).
3. Obtaining parts on forging rolls. Recommendations, Voronezh, ENIKMASH, 1980, (in Russian).
4. Patent of Russian Federation 2255831. Branched forgings forming method, V.S. Martyugin, A.A. Romashov, I.M. Volodin at al., 2005, Bulletin 19, (in Russian).
5. P.I. Polukhin, Resistence of plastic deformation of metals and alloys, in P.I. Polukhin, G.Y. Gunn, A.M. Galkin, Moscow, Metallurgy, 1983, (in Russian).
6. N.V. Makarova, Statistics in Excel, in N.V. Makarova, V.Y. Trofices, Moscow, Finances and statistics, 2003, (in Russian).
7. I.M. Volodin, Statistical analysis of experimental results of research in treatment of metals with pressure, Textbook, I.M. Volodin, P.I. Zolotuhin, Lipetsk, LSTU, 2003, (in Russian).
8. I.V. Telegin, Assessment of metal intensity of hot die forging of forgings from round bars, Science almanac, 2015, 7, 9, 817-821, (in Russian).
9. Li Ru-Xiong, Jiao Song-Hua, Wang Jin-lv, Roll- Forging Technology of Automotive Front Axle Precision Performing and Die Design, IERI Procedia, v. 1, 2012, 166-171.
10. Cai Zhong-Yi, Precision design of roll-forging die and its application in the forming of automobile front axles, Journal of Materials Processing Technology, 168, 1, 2005, 95-101.
11. Yang Shen-hua, Kou Shuqing, Deng Chunping: Research and application of precision roll-forging taper-leaf spring of vehicle, Journal of Materials Processing Technology, 65, 1-3, 1997, 268-271.