SOLUTION OF A SUITABLE METHOD OF PRODUCTION OF CONTACTOR FORGINGS

RADEK CADA, STEPAN MATEJ

Department of Mechanical Technology, Faculty of Mechanical Engineering, VSB – Technical University of Ostrava, Ostrava, Czech Republic

DOI: 10.17973/MMSJ.2023_03_2022100

radek.cada@vsb.cz

This paper discusses a suitable method to manufacture contactor forgings, depending on the size of the series. A suitable semi-finished product and the method of cutting have been proposed. The design of a suitable forming machine and forging tools was carried out for the production of contactor forgings in the number of 10,000 pieces and 50,000 pieces per year. The LE 160 eccentric press was designed to cut the sprue. A comparison was made between the production of contactor forging on the pneumatic-hydraulic hammer KHZ 4 A and the production on the mechanical crank press LKM 1600. The die design was carried out for both production alternatives. The cost analysis for the production of one piece of forging showed that for a large number of pieces, it is more economical to forge using a mechanical forging press.

KEYWORDS

Forging, machine, tool, press, hammer, die, contactor.

1 INTRODUCTION

The technology of hot volume forming is mainly applied in the series production of identical components. It is characterized by high productivity and economics. The products have good mechanical properties, unbroken fibres that follow the shape complexity of the component and the least waste during production. The disadvantage is the energy consumption and high cost of producing a single-purpose tool, a die. Forming has multiple applications in manufacturing due to the minimal waste and low production costs, especially in the mass production of shape-identical components.

The starting material for the production of forgings is bar steel, which is usually produced by continuous casting and hot rolling [Velicka 2013]. The lifetime of forging tools is influenced by their resistance to thermal and abrasive wear [Evin 2019, Tavodova 2020]. Preventing defects in forging tools is possible by using non-destructive detection methods [Stancekova 2013]. To remove burrs and scale from forgings, blasting or tumbling can be used [Cada 2021]. In the case of subsequent welding of fabricated components, the mechanical properties of the material are important, especially in the heat-affected zone [Sternadelova 2019].

The mechanical properties of metallurgical semi-finished products can be increased in some applications, eg, by the unconventional forming method DRECE (Dual Rolls Equal Channel Extrusion) [Rusz 2019, Rusz 2020].

In the manufacturing process, a properly designed maintenance organisation [Necas 2019, Necas 2021, Schindlerova 2021] and the monitoring and prevention of defects [Sproch 2021] are important. The achievement of maximum production productivity while eliminating waste can be achieved, for example, using the value stream mapping method [Sajdlerova 2015] and the good design of the distribution warehouse [Schindlerova 2019].

1.1 *Comparison of Hammer and Press Forging*

When forging on hammers, the cavity of the die is gradually filled with material over several ram strokes. The impact action of the hammer causes a faster flow of the formed material and easier filling of the cavity in the direction of impact. The cavity in the upper part of the die fills better than the lower part and the scales fall off the semi-finished product more easily with the impact of the ram. Hammers are used in small batch and mass production. Machines are characterized by their low energy consumption and wide technological applicability – they are suitable for small forges as well as the main machines of forging sets and lines.

When forging on presses, the die cavity is filled with material in one ram stroke. The calm action of the pressing force causes a better creep of the metal in a direction perpendicular to the applied force. Forgings forged on mechanical presses can have smaller chamfers (ejectors can be used on presses) and are more accurate. When forging on presses, die wear is less because the hot metal is in contact with the die for one single pressing. The main advantages of using presses are uniform forging throughout the forging and the fact that the progression of the pressing force is not impacting but continuously increasing. The disadvantage of forging on presses is that the scales are forged into the forging and thus degrade its surface. Crank presses are more powerful than hammer presses, they also do not need such massive foundations, and they have less demand on the skill and physical strength of the operator. Because of the higher cost of press compared to hammers and because of the higher cost of dies, presses are used only in large-scale or mass production. Forging presses can be easily automated or integrated into entire production lines.

1.2 *Choice of Forging Method in Forges*

In forging shops, it is necessary to decide how to forge a particular forging. Several aspects can be taken into account when making this decision, e.g., the load on the forging lines in the forge, the external shape of the die inserts (square or round), economic considerations, and the desired properties of the forging. This paper discusses the way to decide from an economic point of view between manufacturing a forging on a hammer or a mechanical crank press, depending on the number of forgings to be forged. As a representative of the forgings, a contactor forging was selected, which was previously produced at the die forging plant of FERRUM FORM, Ltd. in a forging line with a gas chamber furnace and pneumatic-hydraulic drop hammer KHZ 4 A (manufacturer joint stock company Smeral Brno) and later, when the number of pieces was increased, on the forging line with induction heating and mechanical crank press LKM 1600 (manufacturer joint stock company Smeral Brno). Thus, it was possible to include objective data on the service life of forging inserts in both forging methods [Matej 2022].

2 TECHNOLOGY OF PRODUCTION OF CONTACTOR FORGINGS

2.1 *Properties of the Forging Used for the Analysis*

For the analysis, a contactor forging with a broken parting plane manufactured from non-alloyed stainless steel for hardening C45E according to EN 10083-2 (formerly designated 12 050 according to the Czech Standard, Ck 45 according to DIN 17200) was selected. The chemical composition of this material is given in Tab. 1. According to EN 10083-2, the recommended temperature range for the hot forming is 1150 to 850 °C.

Element	C	Si	Mn	Cr
Min.	0.42	–	0.50	–
Max.	0.50	0.40	0.80	0.40
Element	Mo	Ni	P	S
Max.	0.10	0.40	0.030	0.035

Table 1. Chemical composition of C45E steel according to EN 10083-2 (wt %)

The dimensions of the contactor forging are shown in Fig. 1. The contactor forging is manufactured in the F forging accuracy grade (i.e., the usual limit deviations) according to EN 10243-1. The contactor forging after burr and needle grinding and after subsequent blasting is shown in Fig. 2. A forging of the contactor after burr and needle grinding, after blasting, and after subsequent machining is shown in Fig. 3.

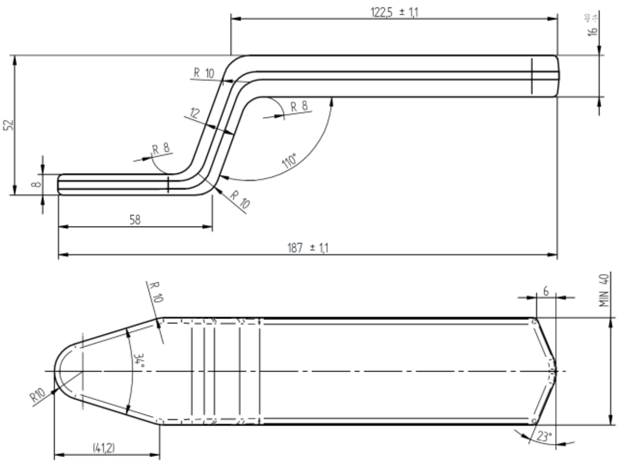

Figure 1. Dimensions of contactor forging

Figure 2. Contactor forging after burr and needle grinding and after subsequent blasting

Figure 3. Contactor forging after burr and needle grinding, after blasting, and after subsequent machining

2.2 Determination of the Volume of the Contactor Forging Semi-Finished Product

To determine the weight of the input semi-finished product, it is necessary to know the volume of the forging, the volume of the material in the forging groove and the volume of the loss of material due to oxidation of surface layers during heating.

The volume of the contactor forging $V_{výk}$ = 105,799.9 mm^3, the projection area of the contactor forging in the division plane S_v = 7,106.5 mm^2 and the circumference of the contactor forging in the division plane O = 425.6 mm were determined using a drawing program.

The dimensions of the forging groove are designed according to the height of its bridge h, which is calculated from the formula:

$$h = \alpha \cdot \sqrt{S_v} \tag{1}$$

where α is the correction factor in a range of values 0.015–0.017, larger values belong to forgings with a circular diameter in the cutting plane. For the non-circular forging, it was chosen α = 0.015 (–), S_v is the area of the forging projection in the parting plane (mm^2).

The height of the bridge of the forging groove for the contactor forging was calculated by inserting the values into equation (1):

$$h = 0.015 \cdot \sqrt{7{,}106.5} = 1.26 \cong 1.6 \text{ mm} \tag{2}$$

The volume of material in the forging groove:

$$V_g = 0.7 \cdot S_g \cdot \left[O + 4 \cdot (b + b_z) \right] \tag{3}$$

where S_g is the cross-sectional area of the forging groove (mm^2), O is the circumference of the forging in the parting plane (mm), b is the width of the forging groove (mm), b_z is the width of the forging groove tray (mm).

The values of b, b_z and S_g were determined according to the value of h from the table of basic dimensions of forging grooves for hammer dies [Dvorak 2000, Cermak 2004, Cada 2015], while the second dimension size was chosen for simply shaped forgings filling the cavity by pressing.

The volume of material in the forging groove for contactor forging was calculated by inserting the values into equation (3):

$$V_g = 0.7 \cdot 113 \cdot \left[425.6 + 4 \cdot (9 + 25) \right] = 44{,}424.9 \text{ mm}^3 \tag{4}$$

The value of the material loss due to oxygenation of the surface layers during heating o [%] is in the range of 1 ÷ 2 % of the total volume of the input semi-finished product, with lower values for induction heating and higher values for heating by the furnace. The forging line with pneumatic-hydraulic hammer KHZ 4 A heats the input material in a gas chamber furnace; therefore, the value of o = 1.8 % was chosen. (When forging the contactor forging on a forging line with a mechanical crank press LKM 1600 and induction heating, it would be appropriate to choose a value of o = 1.2 %.)

Volume of material loss due to oxygenation of the surface layers during heating:

$$V_{ml} = (V_f + V_g) \cdot \frac{o}{100} \tag{5}$$

where V_f is the forging volume (mm^3), V_g is the volume of material in the forging groove (mm^3), o is the loss of material due to oxygenation of the surface layers during heating (%).

The volume of material loss due to oxygenation of the surface layers during heating for the contactor forging forged on the hammer was calculated by inserting the values into equation (5):

$$V_{ml} = (105{,}799.9 + 44{,}424.9) \cdot \frac{1.8}{100} = 2{,}704.0 \text{ mm}^3 \tag{6}$$

Volume of semi-finished product for forging:

$$V_p = V_f + V_g + V_{ml} \tag{7}$$

where V_f is the volume of forging (mm^3), V_g is the volume of material in the forging groove (mm^3), V_{ml} is the volume of material lost due to oxygenation of the surface layers during heating (mm^3).

The volume of the semi-finished product for the contactor forging was calculated by inserting the values into equation (7):

$$V_p = 105{,}799.9 + 44{,}424.9 + 2{,}704.0 = 152{,}928.8 \text{ mm}^3 \tag{8}$$

2.3 Determination of the Weight of the Contactor Forging Semi-Finished Product

It is clear from the shape of the contactor forging that the length of the input semi-finished product will be several times its diameter.

Calculation of the diameter of the semi-finished product from the volume of the semi-finished product and the length of the semi-finished product:

$$V_p = \frac{\pi \cdot D_p^2}{4} \cdot L_p \Rightarrow D_p = \sqrt{\frac{4 \cdot V_p}{\pi \cdot L_p}} \tag{9}$$

The calculation of the preliminary diameter of the semi-finished product for contactor forging was carried out by substituting the volume of the semi-finished product V_p = 152,928.8 mm^3 and the estimated length of the semi-finished product L_p = 200 mm in equation (9):

$$D_p = \sqrt{\frac{4 \cdot 152{,}928.8}{\pi \cdot 200}} = 31.2 \text{ mm} \tag{10}$$

The diameter of the semi-finished product commonly supplied D_p = 30 mm was chosen and the length L_p = 216 mm was calculated from the volume of the semi-finished product using equation (9).

In FERRUM FORM, Ltd. die forging plant, the dimensions of the semi-finished product determined in this way were corrected after a series of technological tests on a forging line with a gas chamber furnace and a pneumatic-hydraulic hammer KHZ 4 A to the values D_p = 30 mm, L_p = 216 mm (hot-rolled round steel bar according to CSN EN 10060).

Weight of the semi-finished product:

$$m_p = V_p \cdot \rho = \frac{\pi \cdot D_p}{4} \cdot L_p \cdot \rho \tag{11}$$

where V_p is the volume of the semi-finished product (mm^3), ρ is the specific weight of the material of the semi-finished product (mm), D_p is the diameter of the semi-finished product (mm), L_p is the length of the semi-finished product (mm).

Weight of the semi-finished product for contactor forging:

$$m_p = \frac{\pi \cdot 30}{4} \cdot 213 \cdot 7{,}833 = 1{,}18 \text{ kg} \tag{12}$$

In FERRUM FORM, Ltd. die forging plant, cutting of metallurgical material (round bars with a diameter of 30 mm) into semi-finished products is carried out by cold cutting on the ScK 250 machine shears (see Fig. 4).

2.4 Production of Dies for KHZ 4 A Hammer

For contactor forging on the KHZ 4 A hammer, a one-cavity die was designed and a block with dimensions of 115 x 115 x 240 mm made of quality material X37CrMoV5-1 (1.2343) was designed as a starting blank for the production of the upper and lower forging inserts. It is a medium alloy tool steel for heat transfer work with very good toughness, wear resistance to heat transfer, and high strength to heat transfer.

Figure 4. Cutting of metallurgical material into semi-finished products by cold cutting with machine shears ScK 250

The designed single-cavity die is also a docking cavity; i.e. its shape corresponds to the shape of the forging, differing only by the difference in material shrinkage from the forging temperature to the ambient temperature. When a contactor forging is made with a hammer, two cavities side by side or behind each other would not fit into any of the sockets used.

The die is composed of an upper forging insert, which is inserted into the upper sleeve, and the lower forging insert, which is inserted into the lower sleeve. The inserts are inserted into the sleeves cold and screwed on at the back with clamps, as shown in Figs. 5 and 6. The upper and lower sleeves are universal. The guiding of the dies is done both by using a lock and by using two guide pins located at the corners of the lower die. Die guides prevent over-engagement and capture pressures that would put excessive stress on the machine guides.

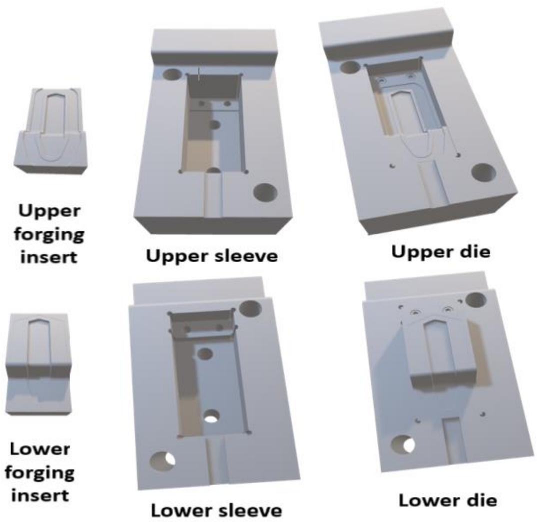

Figure 5. Die design system to forge the contactor forging on the hammer

Figure 6. Lower and upper forging inserts and their positioning in the sleeves for forging the contactor forging on the hammer

The hammer die clamping system is designed using herringbone and longitudinal wedges (see Fig. 7). The clamps have herringbones cut in their lower part, which are inserted into the herringbone groove of the hammer.

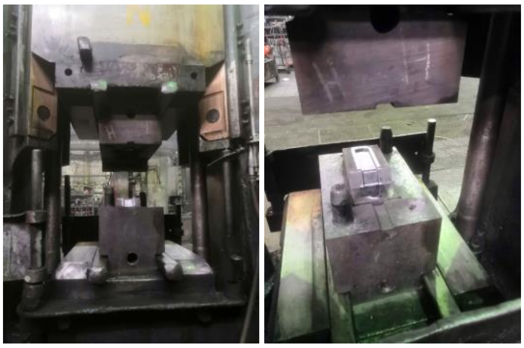

Figure 7. Clamping the lower and upper part of the die to forge the contactor forging on the KHZ 4 A hammer

2.5 Production of Contactor Forging on the KHZ 4 A Hammer

The forging line (see Fig. 8) includes a gas chamber furnace, a pneumatic-hydraulic hammer KHZ 4 A, and a cutting press LE 160.

Figure 8. Forging line to forge the contactor forging on the KHZ 4 A hammer

This forging line is operated by two workers, and the performance standard in the die forging plant of FERRUM FORM, Ltd. is 100 pcs/h. The furnace operator heats a batch of 50 blanks in the furnace to a temperature of 1,150 °C, forges the entire batch, and then repeats the process.

When determining the heating time, the procedure is to achieve the desired forming temperature, the lowest possible thermal stress, uniform heating, low heating energy consumption, and the lowest possible oxidation and decarburisation. The heating time depends on the thickness of the semi-finished product. The higher the heating rate, the shorter the heating time.

To form the material as easily as possible, to shorten forging times and to prevent the dies from wearing so much, the forging is usually carried out at the highest permissible forging temperatures.

The operator places the heated semi-finished product in the center of the lower die (preheated to 200–300 °C) and forges the shape of the forging by repeated strokes. Then the operator of the cutting press cuts the forging.

The shearing tool for shearing the contactor forging on the LE 160 shearing press is shown in Fig. 8. The shearing tool for shearing the contactor forging on the LE 160 shearing press is shown in Fig. 9. The contactor forging with the material that was in the forging groove, the sheared forging and the shearing waste are shown in Fig. 10.

Figure 8. Shear and shear to cut the contactor forging on the LE 160 shearing press

Figure 9. Shearing tool for cutting contactor forgings on the LE 160 shearing press

Figure 10. Contactor forging with the material that was in the forging groove (left), sheared forging (centre), and shearing waste (right)

After the forging is sharpened, the burr and needle are ground on a bench grinder. The contactor forgings are then blasted on a BT 63 blast machine (see Fig. 11) with steel blast-cleaning abrasive No. 9 for a minimum of 15 minutes. The blasted contactor forgings are shown in Fig. 12.

Figure 11. Contactor forging blasting on the BT 63 blast machine

Figure 12. Blasted contactor forgings

2.6 Production of Dies for Mechanical Crank Press LKM 1600

For the forging of the contactor forging on the mechanical crank press LKM 1600, the forging and finishing inserts of the die were designed. As a starting base for the production of upper and lower forging inserts, a block was designed with dimensions of 115 x 115 x 240 mm of material of grade X37CrMoV5-1 (1.2343). It is a medium alloy tool steel for heat sealing work with very good toughness, wear resistance of the heat seal, and high-strength heat seal. The shape of the forging was designed to be narrower and taller than that of the future forging to make the insertion into the docking cavity straightforward. For easier forming in the forging cavity, larger values of the chamfers and edge radii were used compared to those used in the docking cavity. The forging cavity increases the lifetime of the docking cavity.

The die consists of an upper forging and a docking insert which are inserted into the upper sleeve. and a lower forging and a docking insert which are inserted into the lower sleeve. The inserts are inserted into the sleeves in the same way as for hammer fit (see 2.4). The entire system is shown in Fig. 13. The die guiding is done using both a lock and using three guide pins located in the corners of the lower die. The die guides prevent over-positioning and capture pressures that would put excessive stress on the machine guide.

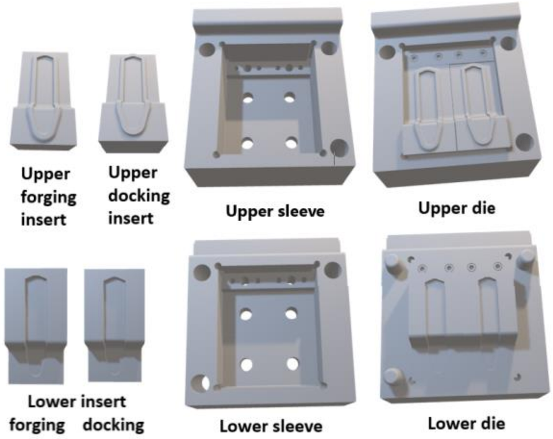

Figure 13. Die design system for forging the contactor forging on the press

The lower sleeve and lower die with two forging inserts to forge the contactor forging on the LKM 1600 press are shown in Fig. 14. The lower and upper inserts of the forging die to forge the contactor forging on the press and clamping with the wedges of the lower square sleeve with the lower inserts of the die on the LKM 1600 press are shown in Fig. 15.

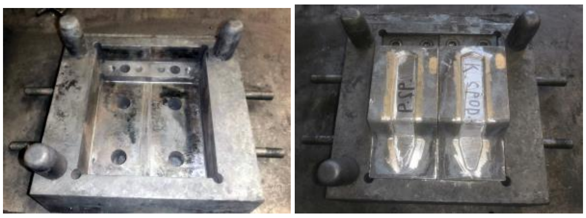

Figure 14. Lower sleeve and lower die with two forging inserts to forge the contactor forging on the LKM 1600 press

2.7 Production of Contactor Forging on Mechanical Crank Press LKM 1600

The forging line (see Fig. 16) includes induction heating, mechanical crank press LKM 1600, and trimming press LE 160. This forging line is operated by three workers, and the performance standard in the die forging plant of FERRUM FORM, Ltd. is 200 pcs/h. The material is loaded into the induction heater, and, after the material is heated to a forging temperature of 1,150–1,050 °C, the forging of the contactor forging is followed by the forging of the contactor forging on the mechanical crank press LKM 1600 (preheated to a temperature of 200–300 °C) and then the sharpening of the contactor forging on the sharpening press LE 160.

Figure 15. Lower and upper inserts of the forging die to forge the contactor forging on the press and clamping with the wedges of the lower square sleeve with the lower inserts of the die on the LKM 1600 press

Figure 16. Forging line to forge the contactor forging on the LKM 1600 press

The clamping of the square sleeves in the LKM 1600 press and the insertion of the blank into the forging cavity of the die for the production of the contactor forging are shown in Fig. 17. The forging of the contactor forging in the forging cavity of the die fixed in the LKM 1600 press and the clamping in the docking cavity of the die are shown in Fig. 18.

Figure 17. Clamp square sleeves in the LKM 1600 press and insert the semi-finished product into the forging cavity of the die for the production of contactor forging

Figure 18. Forging of the contactor forging in the forging cavity of the die fixed in the LKM 1600 press and docking in the die docking cavity

3 LIFE ANALYSIS OF FORGING INSERTS FOR FORGING ALTERNATIVES BY HAMMER OR PRESS FORGING

3.1 The Life of Dies and the Costs of Their Production and Renewal

In FERRUM FORM, Ltd. die forging plant, the inserts are produced from X37CrMoV5-1 material (price 115 CZK/kg). The semi-finished material starting for the production of die inserts for both production methods was a block with dimensions of 115 x 115 x 240 mm with a total weight of 24.5 kg (unit price 2,817.5 CZK).

The service life of dies depends mainly on the type and complexity of the forging shape, the number of forging operations, the material of the die and the blank, the number of working strokes, the forging temperature and the type of lubricant used, etc.

The cost of the dies and their service life were solved for both types of die forging, for a series of 10,000 pieces and a series of 50,000 pieces. The cost of the cutting tool was identical for both production methods and was therefore included in the calculation. Renewal of the cutting tool was considered after the completion of the batch. The sleeves into which the die inserts are inserted were not included in the calculation. The sleeves are versatile and are used for multiple positions and the cost of their manufacture and refurbishment was included in the workshop overhead.

3.2 The Service Life of Die Inserts for Hammer Forging

In FERRUM FORM, Ltd. die forging shop, it was found that after forging approximately 2,000 pieces of contactor forgings on the hammer, a depression was formed in the lower forging insert at the place shown in Fig. 19 by gradual abrasion, which has an undesirable effect on the shape of the contactor forging, and the insert has to be restored by removing a 4 mm thick layer.

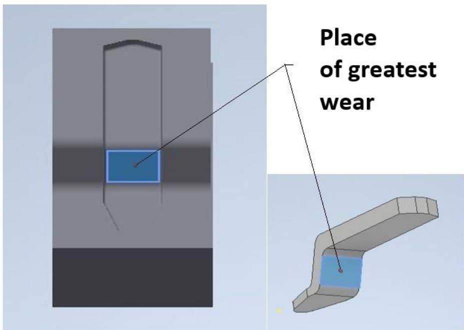

Figure 19. Place of greatest wear of the lower insert of the die during the forging of the contactor forging on the hammer and the corresponding place on the forging

When the contactor is forged on the hammer, it is therefore necessary to renew the die inserts after forging 2,000 pieces. Since the restoration of the shape of the cavity in the die insert reduces the height of the die insert by 4 mm each time, it is possible (given the total height of the die insert) to restore the shape of each insert a total of 10 times. Thus, a maximum of 22,000 contactor forgings can be produced per hammer with one pair of die inserts.

3.3 The Service Life of Die Inserts When Forging on the Press

In FERRUM FORM, Ltd. die forging shop, it was found that after forging approximately 15,000 pieces of contactor forgings on a mechanical forging press, the shape in the front part of both forging inserts of the die cavity in the area around the pointed end of the contactor forging (see Fig. 20) has been deepened by progressive abrasion to such an extent that it has an undesirable effect on the shape of the contactor forging and the insert must be restored by removing a 4 mm thick layer. Increased abrasive wear was found in the same area in the front of both forging inserts of the die docking cavity (see Fig. 20), but its extent was less than that of both forging inserts of the die forging cavity.

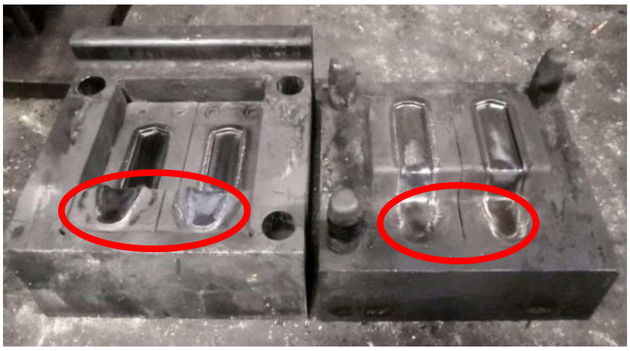

Figure 20. Locations of the greatest abrasive wear on forging inserts Pre-forging cavity (for two guide pins) and finishing cavity (for one guide pin) dies for forging of contactor forgings on the press

In FERRUM FORM, Ltd. die forging plant, all four inserts of the die for the mechanical forging press are still being renewed simultaneously after 15,000 pieces of forging were forged, although the inserts of the forging cavity are more worn than the inserts of the docking cavity. Forging and docking cavity liners are located in one sleeve (upper or lower) so that the liners can be relined after restoration more easily.

4 COST ANALYSIS FOR THE PRODUCTION AND REENEWAL OF FORGING AND CUTTING TOOLS FOR FORGING ALTERNATIVES WITH A HAMMER OR PRESS

4.1 Costs of Manufacture and Refurbishment of Forging and Cutting Tools for Forging Contactor Forgings on the Hammer for a Series of 10,000 Pieces

The costs for the fabrication of forging tools and cutting tools to forge contactor forgings on the hammer are summarised in the Tab. 2. The cost of reworking the forging and cutting tools to forge a series of 10,000 pieces of contactor forgings on the hammer is summarized in the Tab. 3.

Tools	Price of the semi-finished product (CZK)	Price of machining a semi-finished product (CZK)	Cost (CZK)
Upper forging cavity insert	2,817.5	2,200	5,017.5
Lower forging cavity insert	2,817.5	2,200	5,017.5
Staple	950	1,300	2,250
Shearer	535	850	1,385
Wiper	325	520	845
Total cost per 1 piece	**7,445**	**7.070**	**14,515**

Table 2. Cost of forging and cutting tools to forge contactor forgings on the hammer

Tools	Shape restoration price (CZK)	Number of renewals in the series (Pcs)	Recovery costs (CZK)
Upper forging cavity insert	1,500	4	6,000
Lower forging cavity insert	1,500	4	6,000
Trimming tool	1,000	1	1,000
Total cost per 1 piece	–	–	**13,000**

Table 3. Cost of renewing forging and cutting tools for forging a series of 10,000 pieces of contactor forgings on the hammer

4.2 *Costs of Manufacture and Refurbishment of Forging and Cutting Tools for Forging Contactor Forgings on a Press for a Series of 10,000 Pieces*

When contactor forgings were forged on the LKM 1600 crank press, the operation of forming in the preparatory cavity was added (compared to forging on the hammer), i.e., the production of preform inserts was added. These inserts were made from the same block (identical dimensions and material) as the docking die inserts (see 2.6).

The costs for the production of forging and cutting tools to forge contactor forgings on the press are summarized in the Tab. 4.

Tools	Price of the semi-finished product (CZK)	Price of machining a semi-finished product (CZK)	Cost (CZK)
Upper forging cavity insert	2,817.5	2,200	5,017.5
Lower forging cavity insert	2,817.5	2,200	5,017.5
Upper docking cavity insert	2,817.5	2,200	5,017.5
Lower docking cavity insert	2,817.5	2,200	5,017.5
Staple	950	1,300	2,250
Shearer	535	850	1,385
Wiper	325	520	845
Total cost per 1 piece	**13,080**	**11,470**	**24,550**

Table 4. Cost of forging and cutting tools for forging contactor forgings on a mechanical crank press

The cost of refinishing the forging and cutting tools to forge a series of 10,000 pieces of contactor forgings on a mechanical crank press is summarized in the Tab. 5.

Tools	Shape restoration price (CZK)	Number of renewals in the series (Pcs)	Recovery costs (CZK)
Upper forging cavity insert	1,500	0.666	1,000
Lower forging cavity insert	1,500	0.666	1,000
Upper docking cavity insert	1,500	0.666	1,000
Lower docking cavity insert	1,500	0.666	1,000
Trimming tool	1,000	1	1,000
Total cost per 1 piece	–	–	**5,000**

Table 5. Cost of renewing forging and cutting tools to forge a series of 10,000 pieces of contactor forgings on the press

5 COST ANALYSIS OF THE PRODUCTION OF CONTACTOR FORGINGS WHEN FORGING THEM WITH A HAMMER OR PRESS

5.1 *Cost of Producing One Piece of Contactor Forging on a Hammer for a Batch of 10,000 Pieces*

Material costs for the production of one piece of contactor forging:

$$C_{m1} = m_p \cdot P_m = 1.18 \cdot 35.2 = 41.54 \text{ CZK} \quad (13)$$

where m_p is the weight of the semi-finished product (kg), P_m is the price of 1 kg of material (CZK).

Wages of production workers for the production of one piece of contactor forging on a hammer:

$$W_{w1H} = \frac{t_{1H}}{3600} \cdot W_{aH} = \frac{36}{3600} \cdot 266 = 2.66 \text{ CZK} \quad (14)$$

where t_{1H} is the production time of one piece of contactor forging on the hammer (s), W_{aH} is the average hourly wage of the workers involved (CZK).

Since the performance standard of the company FERRUM FORM, Ltd. stipulates the production of 100 pieces of contactor forgings per hour, the production time of one piece is t_{1H} = 36 s. The average hourly wage of a worker is W_{waH} = 133 CZK, that is, for two workers involved in the forging of contactor forgings on the hammer W_{aH} = 266 CZK.

Price of returnable waste:

$$P_w = m_w \cdot P_{1w} = 0.351 \cdot 7.5 = 2.63 \text{ CZK} \quad (15)$$

where m_w is the weight of the waste of a forging piece (kg), P_{1w} is the average purchase price of 1 kg of waste (CZK).

Weight of waste from one piece of contactor forging:

$$m_w = m_p - m_f = 1.180 - 0.829 = 0.351 \text{ kg} \quad (16)$$

where m_p is the weight of the semi-finished product for the forging production (kg), m_f is the weight of the finished forging, i.e., after cutting the material that was in the forging groove (kg).

Workshop overhead for the production of one piece of contactor forging on a hammer:

$$O_{w1H} = \frac{O_w}{100} \cdot W_{w1H} = \frac{1500}{100} \cdot 2.66 = 39.90 \text{ CZK} \quad (17)$$

where O_w is the value of workshop overhead from wages of production workers (%), W_{w1H} is the wages of production workers for the production of one piece of forging per hammer (CZK).

The workshop overhead is set by FERRUM FORM, Ltd. only for the operation of the forge. These are the costs of its operation (e.g., the cost of electricity for the induction heating of forgings and also for the production of compressed air, the cost of gas for heating the chamber furnace), and other costs related to its operation (e.g., the cost of lubricants, work clothes, protective equipment, water, and compressed air).

Company overhead for the production of one piece of contactor forging on a hammer:

$$O_{c1H} = \frac{O_c}{100} \cdot W_{w1H} = \frac{350}{100} \cdot 2.66 = 9.31 \text{ CZK} \quad (18)$$

where O_c is the value of company overhead from the wages of production workers (%), W_{w1H} is the wages of production workers for the production of one piece of forging per hammer (CZK).

Corporate overhead includes the costs of all other operations such as the cutting shop, tool room, quality control department, maintenance, administration, gatehouse, car park, etc.

The workshop and company overhead values in FERRUM FORM, Ltd. were determined on the basis of calculations and calculations for previous accounting periods.

Cost of forging (for hammer) and cutting tools and their renewal per one contactor forging for a series of 10,000 forgings:

$$C_{1H10} = \frac{C_{tH10} + C_{rH10}}{10{,}000} = \frac{14{,}515 + 13{,}000}{10{,}000} = 2.75 \text{ CZK} \quad (19)$$

where C_{tH10} is the cost of forging and cutting tools to forge contactor forgings on the hammer for a series of 10,000 forgings (CZK), C_{rH10} is the cost of renewing forging (for the hammer) and cutting tools for a series of 10,000 forgings (CZK).

5.2 *Cost of Producing One Piece of Contactor Forging on a Mechanical Crank Press for a Series of 10,000 Pieces*

The material costs for the production of one piece of contactor forging are the same as forging on a hammer – according to equation (13) (see 5.1).

Wages of production workers for the production of one piece of contactor forging:

$$W_{w1P} = \frac{t_{1P}}{3600} \cdot W_{aP} = \frac{18}{3600} \cdot 405 = 2.025 \approx 2.03 \text{ CZK} \quad (20)$$

where t_{1P} is the production time of one piece of contactor forging on the press (–), W_{aP} is the average hourly wage of the involved workers (CZK).

Since the performance standard of the company FERRUM FORM, Ltd. stipulates the production of 200 pieces of contactor forgings per hour by forging on the press, the production time of one piece is t_{1P} = 18 s. The average hourly wage of a worker W_{waP} = 133 CZK, i.e., for three workers involved in the forging of contactor forgings on the press W_{aP} = 405 CZK.

The price of returnable waste is the same when forging the contactor forging on a mechanical crank press as when forging it on a hammer – according to equations (15) and (16) (see 5.1).

Workshop overhead for the production of one piece of contactor forging on a press:

$$O_{w1P} = \frac{O_w}{100} \cdot W_{1P} = \frac{1500}{100} \cdot 2.025 = 30.38 \text{ CZK} \quad (21)$$

where O_w is the value of workshop overhead from wages of production workers (%), W_{1P} is wages of production workers for the production of one piece of forging on the press (CZK).

Company overhead for the production of one piece of contactor forging on a press:

$$O_{c1P} = \frac{O_c}{100} \cdot W_{w1P} = \frac{350}{100} \cdot 2.025 = 7.09 \text{ CZK} \quad (22)$$

where O_c is the value of corporate overhead from the wages of production workers (%), W_{w1P} is the wages of production workers for the production of one piece of forging on the press (CZK).

Cost of forging (for press) and cutting tools and their renewal per one contactor forging for a series of 10,000 forgings:

$$C_{1P10} = \frac{C_{tP10} + C_{rP10}}{10{,}000} = \frac{24{,}550 + 5{,}000}{10{,}000} = 2.96 \text{ CZK} \quad (23)$$

where C_{tP10} is the cost of forging and cutting tools for forging contactor forgings on the press for a series of 10,000 forgings (CZK), C_{rP10} is the cost of renewing forging (for the press) and cutting tools for a series of 10,000 forgings (CZK).

5.3 *Comparison of the Cost of Producing One Piece of Contactor Forging with Different Production Methods for a Series of 10,000 Pieces*

A comparison of the total cost of producing one piece of contactor forging on a hammer and a crank press for a series of 10,000 pieces is shown in the Tab. 6.

Item (CZK)	Hammer	Press
Material costs C_{m1}	41,54	41,54
Wages of production workers W_{1H} and W_{1P}	2.66	2,03
Workshop overhead O_{wH} *and* O_{wP}	39,90	30,38
Company overhead O_{cH} *and* O_{cP}	9,31	7,09
Cost of forging and cutting tools and their renewal C_{1H10} *and* C_{1P10}	2,75	2,96
Price of returnable waste P_w	-2,63	-2,63
Total cost per one piece of forging	**93,53**	**81,35**

Table 6. Comparison of the total cost of producing one piece of contactor forging on a hammer and a crank press for a series of 10,000 pieces

The total cost of production of one piece of contactor forging for an annual series of 10,000 pieces when forging on a hammer is 93.53 CZK when forging on a mechanical crank press 81.35 CZK.

Since the cost of refurbishment and production of die inserts is not as frequent when forging on a mechanical forging press as when forging on a hammer, the economic advantage of forging on a mechanical forging press also increases as the number of pieces in a series increases.

5.4 *Comparison of the Cost of Producing One Piece of Contactor Forging with Different Production Methods for a Series of 50,000 Pieces*

When forging on the hammer, it is necessary to renew the forging inserts after forging 2,000 pieces of contactor forgings. Since the restoration of the cavity shape in the die insert reduces its height by 4 mm each time, the shape of each insert (relative to the total height of the die insert) can be restored a total of 10 times. Thus, a maximum of 22,000 contactor forgings can be produced per hammer with one pair of die inserts. For a series of 50,000 contactor forgings, three pairs of die inserts would be used, and a total of 24 shape restorations would be required for these inserts.

Cost of forging (for hammer) and cutting tools and their renewal per one contactor forging for a series of 50,000 forgings:

$$C_{1H50} = \frac{C_{tH50} + C_{rH50}}{50{,}000} = \frac{14{,}515 + 2 \cdot 10{,}035 + 5 \cdot 13{,}000}{50{,}000} = \\ = \frac{34{,}585 + 65{,}000}{50{,}000} = 1.99 \text{ CZK} \tag{24}$$

where C_{tH50} is the cost of forging and cutting tools to forge contactor forgings on the hammer for a series of 50,000 forgings (CZK), C_{rH50} is the cost of renewing forging (for hammer) and cutting tools for a series of 50,000 forgings (CZK).

When forging on a mechanical crank press, it is necessary to renew the forging inserts after forging 15,000 pieces of contactor forgings. For a batch of 50,000 pieces of contactor forgings, three cavity shape restorations of two pairs of die inserts would be required.

Cost of forging (for press) and cutting tools and their renewal per one contactor forging for a series of 50,000 forgings:

$$C_{1P50} = \frac{C_{tP50} + C_{rP50}}{50{,}000} = \frac{24{,}550 + 25{,}000}{50{,}000} = 0.99 \text{ CZK} \tag{25}$$

where C_{tP50} is the cost of forging and cutting tools for forging contactor forgings on the press for a series of 50,000 forgings (CZK), C_{rP50} is the cost of renewing forging (for press) and cutting tools for a series of 50,000 forgings (CZK).

A comparison of the total cost of producing one piece of contactor forging on a hammer and a crank press for a series of 50,000 pieces is shown in the Tab. 7. The total cost of production of one piece of contactor forging for a series of 50,000 pieces when forging on a hammer is 92.77 CZK when forging on a mechanical crank press 79.38 CZK.

Item (CZK)	Hammer	Press
Material costs C_{m1}	41.54	41.54
Wages of production workers W_{1H} and W_{1P}	2.66	2.03
Workshop overhead O_{wH} *and* O_{wP}	39.90	30.38
Company overhead O_{cH} *and* O_{cP}	9.31	7.09
Cost of forging and cutting tools and their renewal C_{1H} *and* C_{1P}	1.99	0.99
Price of returnable waste P_w	-2.63	-2.63
Total cost per one piece of forging	**92.77**	**79.38**

Table 7. Comparison of the total cost of producing one piece of contactor forging on a hammer and a crank press for a series of 50,000 pieces

6 DETERMINATION OF THE NUMBER OF PIECES IN THE SERIES FROM WHICH IT IS ECONOMICAL TO FORGE THE CONTACTOR FORGING ON THE PRESS

Cost of forging (for hammer) and cutting tools and their renewal per one contactor forging for a series of *n* pieces of forgings:

$$C_{1Hn} = \frac{C_{tHn} + C_{rHn}}{n} = \frac{14{,}515 + 0}{n} \tag{26}$$

where C_{tHn} is the cost of forging and cutting tools for forging contactor forgings on the hammer for a series of *n* pieces of forging (CZK), and C_{rHn} is the cost of renewing forging (for hammer) and cutting tools for a series of *n* forgings (CZK).

Cost of forging (for press) and cutting tools and their renewal per one piece of contactor forging for a series of *n* pieces of forgings:

$$C_{1Pn} = \frac{C_{tPn} + C_{rPn}}{n} = \frac{24{,}550 + 0}{n} \tag{27}$$

where C_{tPn} is the cost of forging and cutting tools for forging contactor forgings on the press for a series of *n* pieces of forging (CZK), and C_{rPn} is the cost of renewing forging (for press) and cutting tools for a series of *n* forgings (CZK).

The number of pieces in a series from which it is economical to forge contactor forgings on a press can be determined by the total cost of producing one piece of contactor forging by forging on a hammer and a crank press, so that for a finite number of pieces *n* they should be approximately equal to:

$$C_{m1} + W_{1H} + O_{wH} + O_{cH} + C_{1Hn} - P_w = C_{m1} + W_{1P} + O_{wP} + \\ + O_{cP} + C_{1Pn} - P_w \tag{28}$$

By substituting equations (27) and (28) into equation (16):

$$W_{1H} + O_{wH} + O_{cH} + \frac{C_{tHn} + C_{rHn}}{n} = W_{1P} + O_{wP} + O_{cP} + \\ + \frac{C_{tPn} + C_{rPn}}{n} \tag{29}$$

After adjusting equation (29) by multiplying *n*:

$$n \cdot (W_{1H} + O_{wH} + O_{cH}) + C_{tHn} + C_{rHn} = n \cdot (W_{1P} + O_{wP} + O_{cP}) + \\ + C_{tPn} + C_{rPn} \tag{30}$$

After adjusting equation (30) to express the variable *n*:

$$n \cdot (W_{1H} + O_{wH} + O_{cH}) - n \cdot (W_{1P} + O_{wP} + O_{cP}) = C_{tHn} + \\ + C_{rHn} - C_{tPn} - C_{rPn} \tag{31}$$

The number of pieces in the series from which the forging of the contactor forging on the press is economical:

$$n = \frac{C_{tHn} + C_{rHn} - C_{tPn} - C_{rPn}}{W_{1H} + O_{wH} + O_{cH} - W_{1P} - O_{wP} - O_{cP}} \tag{32}$$

When substituted in equation (32):

$$n = \frac{24{,}550 + 0 - 14{,}515 - 0}{2.66 + 39.90 + 9.31 - 2.03 - 30.38 - 7.09} = 811.2 \tag{33}$$

Starting from 812 pieces of contactor forging, it is economically preferable to forge it on a mechanical crank press rather than on a hammer.

7 CONCLUSIONS

This paper focused on selecting a suitable method of forging production, depending on the size of the series. As a representative of the forgings a contactor forging with a broken parting plane was used, which is produced from non-alloyed stainless steel for hardening C45E according to EN 10083-2 in the FERRUM FORM, Ltd. die forging shop.

In FERRUM FORM, Ltd. die forging shop, the service life of the forging inserts was determined when contactor forgings were forged on a hammer (2,000 pieces of forging) and when forging them on a mechanical crank press (15,000 pieces of forging).

For a batch size of 10,000 pieces and 50,000 pieces, the cost of producing one piece of contactor forging on both a hammer and a mechanical crank press was calculated and compared. In both cases, it is economically more advantageous to forge the contactor forging on a mechanical crank press. Since the cost of refurbishing and producing die inserts is not as frequent with mechanical crank press forging as it is with hammer forging, the economic advantage of forging the forging on a mechanical crank press also increases as the number of batches increases.

Using the total cost of producing one piece of contactor forging by forging on the hammer and the crank press, the number of pieces in the series from which it is economical to forge the forging on the press was calculated. After the numerical values for forging the selected contactor forgings were obtained, a batch size of 812 forgings was calculated, from which it is more economical to forge on a mechanical crank press rather than forging on a hammer.

The procedure mentioned can be applied to analogous cases of die forging.

ACKNOWLEDGMENTS

This work was supported by the SP2022/14 specific research project at the Faculty of Mechanical Engineering of VSB – – Technical University of Ostrava.

REFERENCES

[Cada 2003] CADA, R. Testing of Strain in Stampings by Embossed Grids. *Technical Gazette*, 2003, Vol. 10, No. 3-4, pp. 9-13. ISSN 1330-3651.

[Cada 2015] CADA, R. *Forming, Casting, and Welding Technologies: Volume Hot Forming, Casting: Instructions for Exercises: Scriptum.* Ostrava: VSB – Technical University of Ostrava, 2015. 128 p. ISBN 978-80-248-3833-5. (in Czech)

[Cada 2021] CADA, R. and LOSAK, P. Comparison of Deburring Technologies after Pipe Cutting. In: *Proceedings of the 30th Anniversary International Conference on Metallurgy and Materials METAL 2021.* 1. vyd. Brno: TANGER, Ltd., 2021, pp. 585-591. ISSN 2694-9296, ISBN 978-80-87294-99-4.

[Cermak 2004] CERMAK, J. *Die Forging* [online]. Prague: Czech Technical University 2004 [cit. 2022-08-11]. Available from: <http://u12133.fsid.cvut.cz/assets/Uploads/vykovek-zadani.pdf?msclkid=f4a1d88ad11411ec96bae30538c2fcdc>. (in Czech)

[Dvorak 2000] DVORAK, M. et al. *Forming Technologies: Instructions for Exercises*. Brno: CERM, 2000. 103 p. ISBN 80-214-1723-4. (in Czech)

[Evin 2019] EVIN, E. and TOMAS, M. Tribology Properties Evaluation for Friction Pair Zn Coated Steel-TiCN MP Coated/Uncoated Tool Steel. *Acta Metallurgica Slovaca*, 2019, Vol. 25, No. 4, pp. 208-216. ISSN 1335-1532, eISSN : 1338-1156.

[Matej 2022] MATEJ, S. *Design of the Production Technology of Contactor Forgings*: *Master's Thesis*. Ostrava: VSB – Technical University of Ostrava, 2022, 59 p. (in Czech)

CONTACT:

prof. Ing. Radek Cada, CSc.
VSB – Technical University of Ostrava, Faculty of Mechanical Engineering, Department of Mechanical Technology
17. listopadu 2172/15, Ostrava-Poruba, 708 00, Czech Republic
+420597323289, radek.cada@vsb.cz, www.fs.vsb.cz

[Necas 2019] NECAS, L. Training and Practice to Ensure Implementation of the TPM System. *Modern Machinery (MM) Science Journal*, Vol. 12, No. 2 (June), 2019, pp. 4124-4127. ISSN 1803-1269, eISSN 1805-0476.

[Necas 2021] NECAS, L. and NOVAK, J. Networking of Maintenance Entities for Production and Other Processes. *Modern Machinery (MM) Science Journal.* 2021, Vol. 14, No. 6, pp. 5410-5413. ISSN 1803-1269, eISSN 1805-0476.

[Rusz 2019] RUSZ, S. et al. Influence of SPD Process on Low-Carbon Steel Mechanical Properties. *Modern Machinery (MM) Science Journal*, Vol. 12, No. 2, 2019, pp. 2910-2914. ISSN 1803-1269, eISSN 1805-0476.

[Rusz 2020] RUSZ, S. et al. Effect of Severe Plastic Deformation on Mechanical and Fatigue Behavior of Medium-C Sheet Steel. *Journal of Mining and Metallurgy: Section B-Metallurgy*, Vol. 56, No. 2, 2020, pp. 161-170. ISSN 1450-5339, eISSN 2217-7175.

[Sajdlerova 2015] SAJDLEROVA, I. et al. Potential of Value Stream Mapping Utilization in the Seamless Steel Tubes Manufacturing Process. In: *24th International Conference on Metallurgy and Materials (Metal 2015).* Ostrava, Czech Republic: TANGER, Ltd., 2015, pp. 2056-2064. ISSN 2694-9296. ISBN 978-80-87294-58-1.

[Schindlerova 2019] SCHINDLEROVA, V. et al. Potential of Using Simulation for the Design of Distribution Warehouse. In: 8th Carpathian Logistics Congress on Logistics, Distribution, Transport and Management (CLC). Prague, Czech Republic: TANGER, 2019, pp. 802-807.

[Schindlerova 2021] SCHINDLEROVA, V. and SAJDLEROVA, I. Comparison of Basic Maintenance Concepts Using Witness. *Modern Machinery (MM) Science Journal*. 2021, Vol. 14, No. 6, pp. 5435-5440. ISSN 1803-1269, eISSN 1805-0476.

[Stancekova 2013] STANCEKOVA, D. et al. Investigation of Defects in Forging Tools by Non-destructive Detection Method. In: *22nd International Conference on Metallurgy and Materials (Metal 2013).* Ostrava, Czech Republic: TANGER, 2015, pp. 485-490. ISSN 2694-9296. ISBN 978-80-87294-39-0.

[Sternadelova 2019] STERNADELOVA, K. et al. Properties and Microstructure of Modeled Heat-Affected Zone of P92 Steel. In: *28th International Conference on Metallurgy and Materials METAL 2019).* Ostrava, Czech Republic: TANGER, 2019, pp. 832-836. ISSN 2694-9296. ISBN 978-80-87294-92-5.

[Sproch 2021] SPROCH, F. and NEVIMA, J. Use of Smart 3D Printing Technology in Conventional Engineering Production to Detect and Prevent the Occurrence of Defects. *Modern Machinery (MM) Science Journal.* 2021, Vol. 14, No. 6, pp. 5441-5447. ISSN 1803-1269, eISSN 1805-0476.

[Tavodova 2020] TAVODOVA, M. and HNILICA, R. Assessment of Selected Properties of Treated Tool Surfaces Examined to Increase Tool Life Time. In: *Manufacturing Technology*. 2020, Vol. 20, No. 2, pp. 257-264. ISSN 1213-2489.

[Velicka 2013] VELICKA, M. et al. Research of Thermal Processes for the Continuous Casting of Steel. *Materiali in Tehnologije*. 2013, Vol. 47, No. 6, pp. 815-818. ISSN 1580-2949.