A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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AN ANALYSIS OF THE INDUSTRIAL FORGING PROCESS OF FLANGE IN ORDER TO REDUCE THE WEIGHT OF THE INPUT MATERIAL

ANALIZA PRZEMYSŁOWEGO PROCESU KUCIA ODKUWKI KOŁNIERZA W CELU ZMNIEJSZENIA MASY MATERIAŁU WSADOWEGO

This paper presents an analysis of the industrial process of hot forging a flange. The authors developed several thermomechanical models of the forging process for which they carried out computer simulations using the MSC.Marc 2013 software. In the Jawor Forge flanges with a neck are manufactured by hot forging in crank presses with a maximum load of 25 MN. The input material, in the form of a square bar, is heated up to a temperature of 1150°C and then formed in three operations: upsetting, preliminary die forging and finishing die forging. The main aim of the studies and the numerical analyses, in which the geometry of the tools would be modified, was to maximally reduce the amount of the input material taking into account the capabilities of the Jawor Forge, and consequently to significantly reduce the production costs. Besides the Forge's equipment resources, the main constraint for modifications was the flange-with-neck forging standard which explicitely defines the tolerances for this element. The studies, which included numerical modelling, infrared measurements and technological tests, consisted in changing the geometry of the tools and that of the forging preform. As a result, the optimum direction for modifications aimed at reducing the mass of the input material was determined. The best of the solutions, making it possible to produce a correct forging in the Jawor Forge operating conditions, were adopted whereby the weight of the preform was reduced by 6.11%. Currently research is underway aimed at the application of the proposed and verified modifications to other flange forgings.

Keywords: numerical modeling, forging, optimisation

Artykuł dotyczy analizy przemysłowego procesu kucia matrycowego na gorąco odkuwki typu kołnierz. Autorzy publikacji opracowali szereg modeli termomechanicznych procesu kucia, dla których przeprowadzili symulacje komputerowe z zastosowaniem oprogramowania MSC.Marc 2013. Przemysłowy proces wytwarzania kołnierzy z szyjką w kuźni Jawor wykonuje się metodą kucia na gorąco na prasach korbowych pracujących z maksymalnym obciążeniem 25 MN. Materiał wsadowy w postaci pręta kwadratowego jest nagrzewany do temperatury 1150°C i następnie kształtowany z wykorzystaniem trzech operacji – spęczania, matrycowania wstępnego oraz matrycowania wykańczającego. Głównym celem przeprowadzanych badań i analiz numerycznych polegających na modyfikacji geometrii narzędzi było jak największe ograniczenie wielkości materiału wsadowego przy jednoczesnym uwzględnieniu możliwości technologiczno-technicznych Kuźni Jawor. Miało to pozwolić na znaczącą redukcję kosztów produkcji. Za największy ogranicznik przeprowadzanych modyfikacji poza parkiem maszynowym zakładu przyjęto normę kucia kołnierzy z szyjką, która w jednoznaczny sposób definiuje tolerancje wykonywanego elementu. Przeprowadzone badania polegające na zmianie geometrii narzędzi i przedkuwki, obejmujące modelowanie numeryczne, pomiary termowizyjne oraz próby technologiczne pozwoliły określić optymalny kierunek wprowadzanych modyfikacji procesu umożlwiający redukcję masy materiału wsadowego. Przyjęcie przez autorów najlepszego z możliwych do uzyskania w warunkach Kuźnia Jawor rozwiązań pozwoliło na zmniejszenie masy wstępniaka o 6,11% w stosunku do masy wyjściowej. Obecnie trwają dalsze prace badawcze związane z przełożeniem zaproponowanych i zweryfikowanych zmian na inne odkuwki kołnierzowe.

1. Introduction

Because of the increasingly free flow of goods and the difficult situation on the market, forges put great emphasis on competitiveness. According to the data contained in [2], in 2013 39% of the production came from China which country, owing to relatively cheaper labour and less restrictive environmental standards, poses serious competition to the domestic plants. The simplest way to attract potential customers is to ensure a low price of the product while maintaining its high quality. These are the guidelines which the larger European manufacturers follow [8]. It is estimated that over 50% of the total product costs are material costs [4], about 20% of which are material losses [6, 10, 11, 13]. Therefore the reduction of material costs is regarded to be the most effective way of reducing the price of forgings at a minimum change in their

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properties [1, 7]. Today IT tools based on computer simulation play a major role in the design of not only engineering constructions, but also industrial processes. As the power of computing machines increases, software based on advanced numerical methods, such as the finite element method, has considerably developed in recent years [3, 5, 9, 12, 14, 15]. Today there is a relatively wide choice of software dedicated to nonlinear problems, such as the plastic deformation of metals. The computer programs become indispensable tools for engineers and can contribute to the improvement of the existing technological solutions. Thanks to the use of FEM-based computing software packages by process and design engineers the latter can quickly analyze forging processes and determine their key features, such as: the distribution of stress and strain, the way the material flows and the process force parameters. Today forging plants in collaboration with scientific and research centres (equipped with much more advanced IT tools and laboratories) can optimize their industrial processes not only to make them more efficient and to improve the quality of the forgings, but also to lower the production costs.

2. Description of process

The hot forging of a flange with a Ø80 neck was selected to be studied. Flange Ø80 is typical axisymmetrical part used to connect pipes. Forging part drawing with exemplary dimensions has been show on Figure 1.

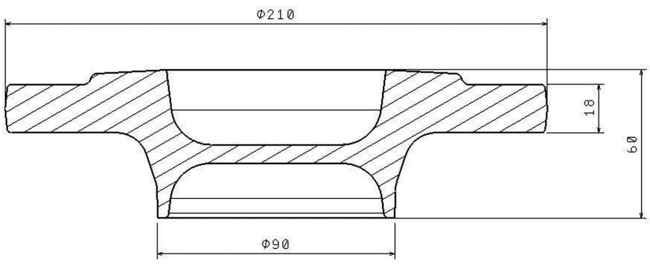

Fig. 1. Final forging with exemplary dimensions

The forging process is conducted in a crank press with a maximum pressure of 25 MN. The preform is heated up to a temperature of 1150°C and then shaped in three operations: upsetting, preliminary die forging and finishing die forging. Figure 2 shows the preforms after the first two operations, and the finished product. In the analyzed process the main aim of upsetting is to give the blank a preliminary shape to make it easier to fill the die impression in the next operations and remove the scale. The product gets the initial proper shape in the course of preliminary die forging while finishing forging is responsible for its sizing to the final dimensions (mainly the radii of the roundings, and selected dimensions) consistent with the customer's specifications. The material properties for steel C.22 for forging part were taken from the software MSC.Marc 2013 database.

3. Numerical modelling of analyzed process

Computer simulations were run, using the MSC MARC 2013 software, in order to determine the principal parameters of the forging process. A 3D model and Tetra 4 elements were used in the simulation, which was divided into three stages corresponding to the particular operations.

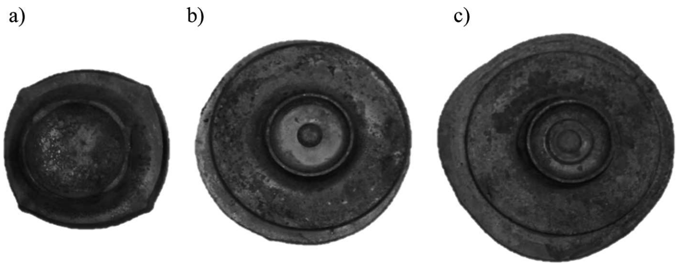

Fig. 2. Shape of forging after particular forging operations: a) upsetting, b) preliminary die forging c) finishing die forging

The tools were assumed as stiff bodies with constant temperature of 300°C and according to symmetry of process the analysis was limited to 1/8 of the model. The constant friction factor of 0.35 has been assumed based on author experience. Heat transfer coefficient between workpiece and tool has been set to 20000 W/(m^2*K) and between workpiece and environment to 35 W/(m^2*K). Such factors as: the temperature of the material, the plastic strains in the forging, the load of the press, the shape of the flash and the filling of the die impressions, were taken into consideration.

Figure 3 shows load press versus press slide for the particular operations obtained in modelling. During preliminary forging and finishing forging the press forces increase sharply at the final moment of filling the die impression, reaching 25 MN. In the case of upsetting, the increase is much gentler and it does not exceed 3 MN. It is apparent from the diagram that the forces do not significantly exceed the maximum load of crank press, which means that the original process has been correctly designed for the press with a nominal force of 25 MN. The characteristic raggedness of the upper part of the diagram at the maximum load is due to the use a remeshing algorithm.

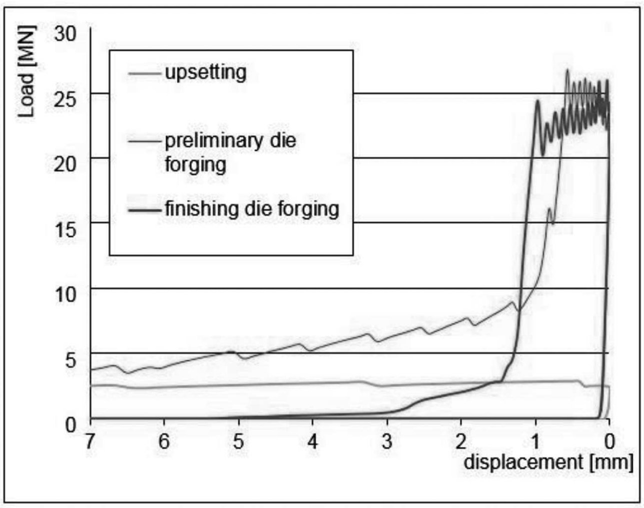

Fig. 3. Load of press versus distance from bottom dead centre

Also the distribution of the temperature in the forging was modelled and towards the end of the second operation a considerable cooling was observed in the lower part of the neck (the area marked in Fig. 4), where the temperature reaches

540°C. It was found that the drop in temperature may significantly contribute to the increase in the forces in the second and third operations and result in the incomplete filling of the die impression. This was confirmed by observations of the real forgings in which underfills would occur in those places.

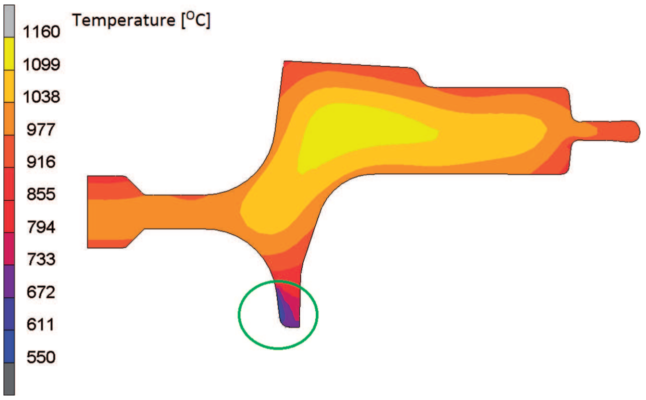

Fig. 4. Distribution of temperature in forging after second operation, with marked area of greatest overcooling

A considerable increase in the length of the flash was also observed between the second operation and the third operation, which is due to the large differences between the shapes of the impressions, leading to the considerable flow of the material in the third operation (intended to perform mainly the calibrating function) (Fig. 5).

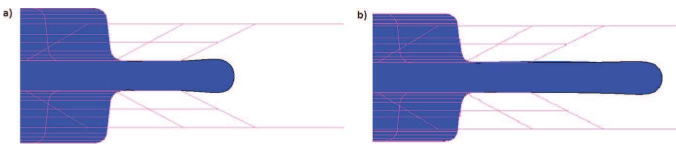

Fig. 5. Flash length after: a) preliminary die forging, b) finishing die forging

4. Assumptions for modifications

The main aim of the modifications was to maximally reduce the amount of input material in order to lower the production costs. Besides the technical capabilities of the Jawor Forge, the tightest constraint on any modifications was standard PN-1092-1 for the forging of flanges with a neck, which explicitly defines the tolerances for this element.

It was decided to reduce selected forging dimensions and the maximum forging force. For this purpose the temperature of the flange neck was to be increased by lowering the bottom and reducing the angle of inclination of the bottom knock-outs and the thickness of the bottom (functioning as an internal flash) situated in the centre of the forging. In addition, in order to maximally reduce the flash forming in the third operation, the difference in the die inserts between the second operation and the third operation was reduced.

5. Modifications made

In order to gain maximum insight into the effect of the modifications on the process the former were introduced gradually and it was analyzed how each of them changed the forging conditions. Figure 6 schematically shows the original and modified profiles of the impressions of the tools used for preliminary forging and finishing forging.

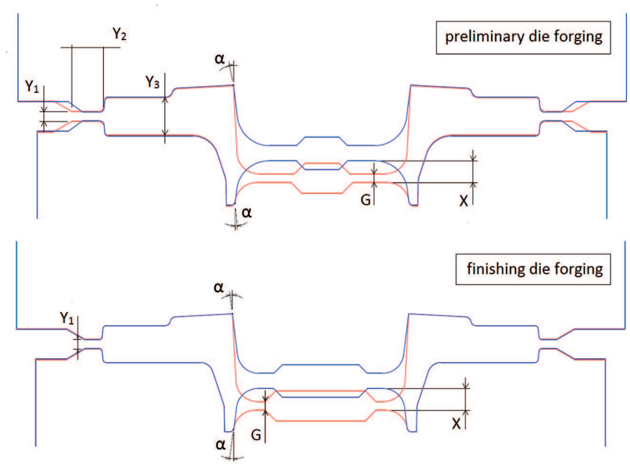

Fig. 6. Comparison of shape of die impressions before and after modification for preliminary die forging and finishing die forging (modified dies are in red)

First the angle of inclination (α) of the bottom knock-outs was reduced by 4 degrees for both preliminary forging and finishing forging. Considering that the temperature of the material being in contact with the knock-outs is relatively high, this modification should not have a significant effect on the load of the press while the presence of the knock-outs in the two operations should prevent the forgings from wedging on the inserts. The obtained results confirmed the insignificant effect of the inclination of the load of the press (Fig. 7).

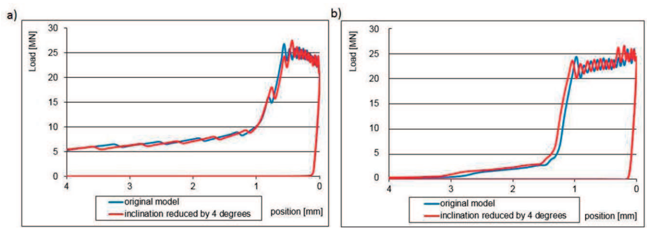

Fig. 7. Comparison of press load as function of distance from bottom dead centre for preliminary die forging (a) and finishing die forging (b)

Then the bottom was shifted by 10 mm towards the neck and its thickness was reduced by 4 mm (denoted as X and G in figure 6). The aim was to reduce the amount lost as flash and at the same time to increase the temperature of the most overcooled point, which was to compensate for the increase in load resulting from the thinning of the bottom. Owing to this modification the area with lowered temperature was reduced and its temperature was increased by about 50°C. A comparison of the effect of the modifications on the distribution of temperature is shown in Fig. 8.

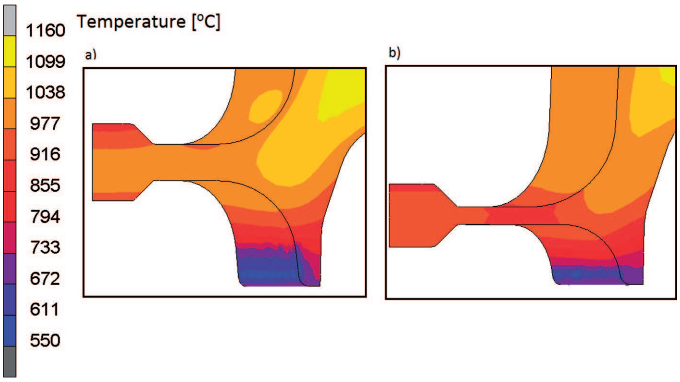

Fig. 8. Distribution of temperature in lower part of forging after finishing operation for a) model before modification and b) model in second stage of modification

The change in bottom thickness with the simultaneous increase of neck temperature had a beneficial effect on the load of the press (fig. 9) and together with the change of the inclination angle resulted in both an overall reduction in the weight of the charge by 3.98% and a reduction of the maximum force loading the press.

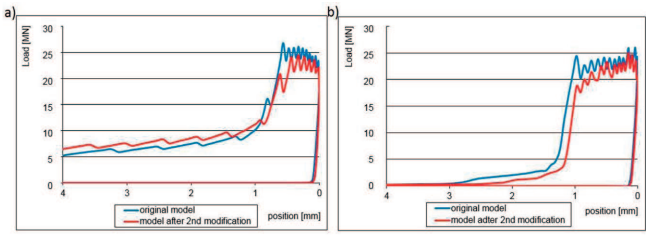

Fig. 9. Comparison of press load as function of distance from bottom dead centre for preliminary die forging (a) and finishing die forging (b) in second stage of modification

The final modification consisted in reducing the thickness of the flange in the second operation by 0.7 mm (denoted as Y_3 in the figure). The aim was to reduce the difference in shape between preliminary forging and finishing forging and thereby limit excessive flash after the third operation. In order to prevent an excessive increase in the force the bridge opening was increased for the two die forging operations. In addition, because of the intensive wear of the bridge during preliminary forging its width was increased by 5 mm.

After a thorough analysis of the degrading mechanisms which occur in these tools a decision was made to slightly increase the thickness of the bottom of the die inserts in order to prevent their excessive abrasive wear and fracturing. The totality of the changes is denoted with the letter Y in the figure.

Owing to bridge opening the increase in the share of forming in preliminary forging did not contribute to any increase in the load of the press in this operation whereby the forces in the final operation decreased considerably: after the modifications their maximum value does not exceed 20 MN (Fig. 10). Moreover, the difference in length between the second- and third-operation flashes was reduced whereby the total charge weight was reduced by 6.11%.

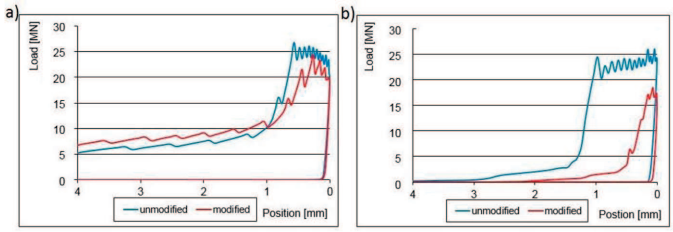

Fig. 10. Comparison of press load versus distance from bottom dead centre for preliminary die forging (a) and finishing die forging (b) in third stage of modification

6. Verification of modelling by experiment

Forging tests (taking into account the proposed modifications) in industrial conditions were carried out in order to verify the results of the FEM analysis. In case of computing errors, preforms with an ever smaller mass, beginning with the nominal mass specified in the technology, were prepared for the tests. In the course of the technological tests the temperature of the tools was controlled by means of a thermal imaging camera so that it was possible to determine the temperature of forgings in various areas (Fig. 11). On the presented thermograms the temperature in subsequent forging operations is rapidly declining, which is confirmed by the results of numerical modeling (Fig. 8).

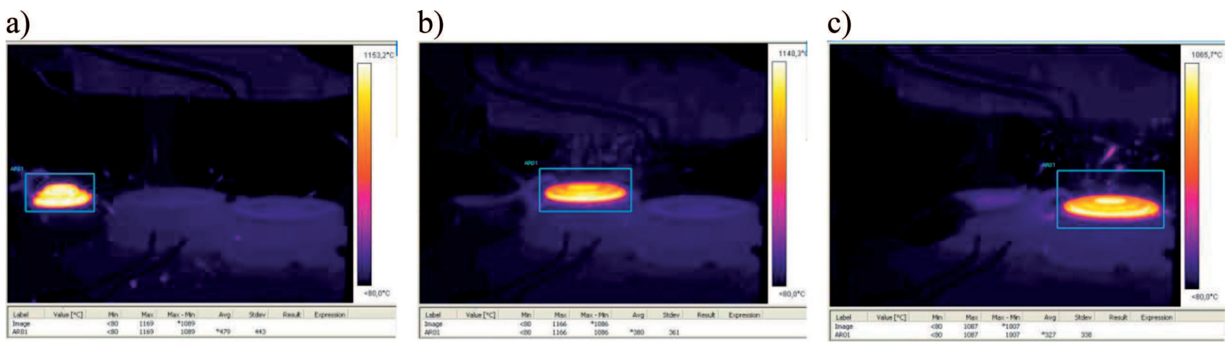

Fig. 11. Thermogram from thermal imaging camera after particular forging operations: a) upsetting, b) preliminary die forging c) finishing die forging

In the tests full tool impression filling was obtained for each of the preform masses. Moreover, no other irregularities (e.g. material jamming) were found. The shape of the flanges with a flash after the second and third operation is compared in Fig. 12.

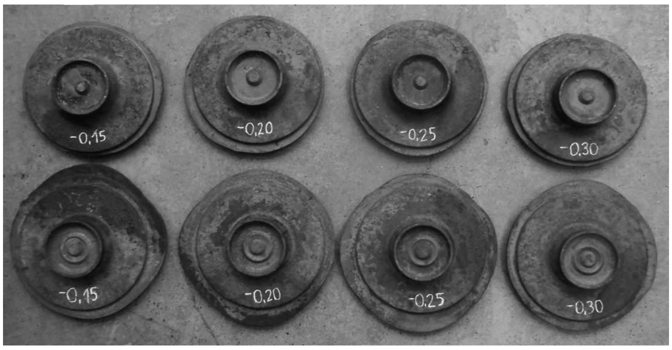

Fig. 12. Comparison of shape of upper part of flange with flash after second operation (top row) and third operation for for every mass lowering (in kilograms)

The dimensional and shape examination of the finished product revealed that in some cases a burr had formed in the upper part of the flange neck, probably as a result of the lowering of the bottom (leading to material burring during die shearing, Fig. 13). But this defect does not affect the quality of the product and it would occur also in the "original process" and the place where it occurs is anyway machined by turning.

Fig. 13. Burr forming as result of bottom shearing

7. Conclusion

The main parameters of the forging process were determined through FEM-based numerical modelling and technological tests. The key factors having influence on the load and the final shape of the product were identified and on this basis several modifications were gradually introduced whereby their effectiveness and effect on the whole process could be studied. The best of the solutions, making it possible to produce a correct forging in the Jawor Forge operating conditions, were adopted whereby the weight of the preform was reduced by 6.11%.

However, due to the imperfection of the finite element method and to the adopted simplifications it was necessary to carry out a verification, which confirmed the satisfactory effectiveness of the modifications. Full filling of the die impression was obtained for each of the masses.

Still, many important factors, such as the stresses generated in the tools and the wear of the latter, were not taken into account. The modelling and the tests merely indicated the direction of the introduced modifications is correct. In order to fully validate the modifications they need to be implemented in the actual manufacturing process and then their mass production effect should be analyzed.

Currently research is underway aimed at the further modification of the process, using the Rozenbrock optimization method, and at the application of the proposed and verified modifications to other flange forgings.

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