**International Students Olympiad in Hot Bulk Forging Technologies**

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# Task

Develop and substantiate the production process according to the ‘Flange’ part drawing (Figure 1), design a forged part drawing, perform the simulation of the process in the QForm software, and analyze the simulation results.

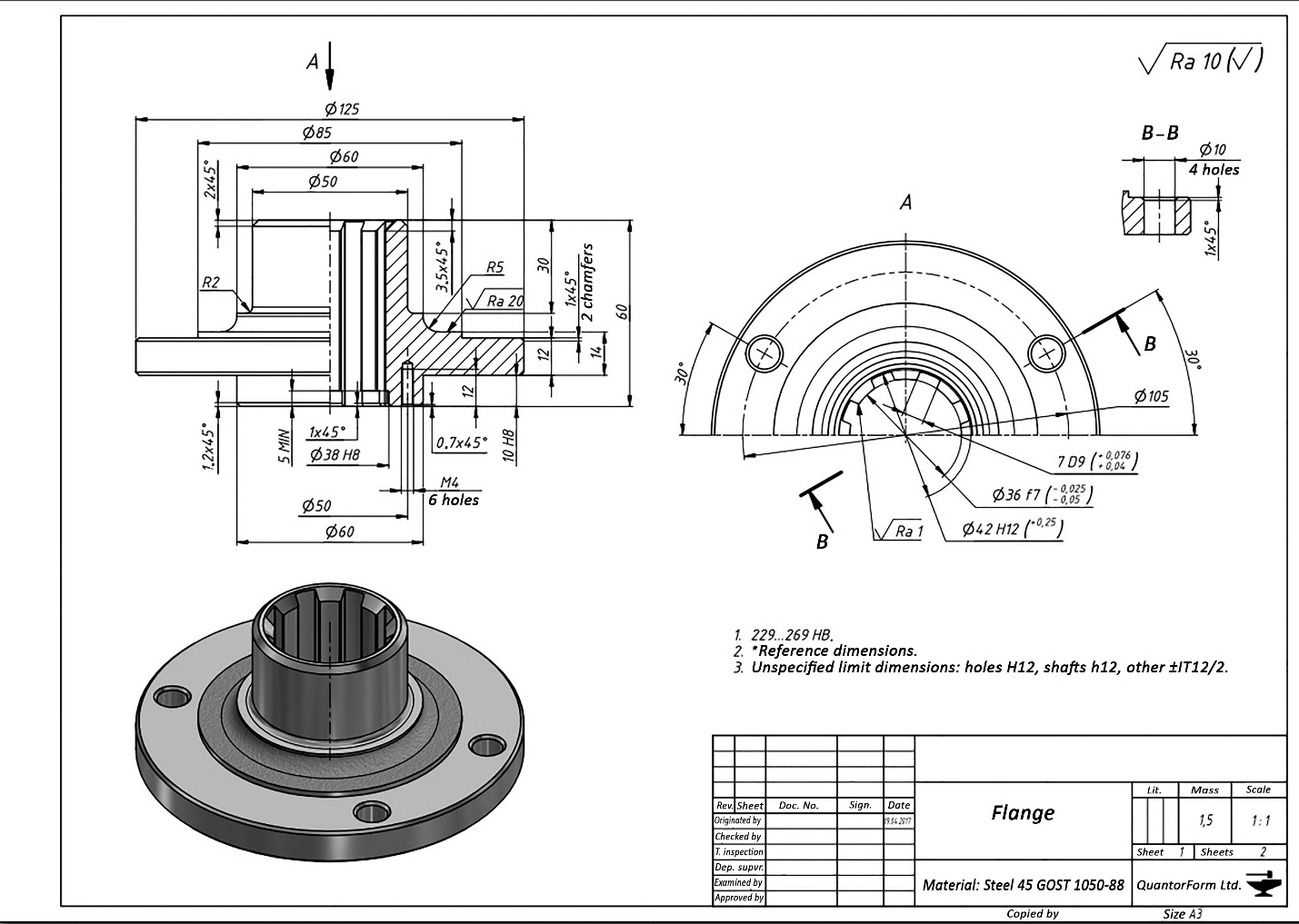


Figure 1. Drawing of the part.

Initial data:

* Material: Steel 45 GOST 1050-88.
* Part weight: 1.5 kg.
* Production volume: large-issue (production of 30,000 pcs).
* Forging equipment: Hydraulic Press (1 unit – 10 MN), steam hammer (1 unit of 2 tons).
* Heating of the workpieces: Not specified.

# Cold forged piece design

## Part shape analysis

The «Flange» is a relatively small part with high thin elements, which is likely to complicate the uniform metal flow during forging operation, complete filling of the die impression and ease of forging extraction. This axis-symmetric part, which is the body of rotation, is convenient to be forged to the end surface of the workpiece in order to provide uniform properties by the perimeter of finished part. The undercuts/cavities on the lateral surfaces of the part (i.e. cavities in the forged part with axes not coincident with the direction of die tool displacement) will be filled with the metal of padding. The mark (web) is provided on the Ø36 hole place for the metal saving purpose.

The following operations have selected for production of the specified part, according to its configuration and taking into account recommendations from the metal forming handbooks [1-5]: Upsetting with expansion and finish forging in an open die. In the case of using open die forging, a certain part of metal will fill the specially designed gutter. It slightly reduces the material utilization factor (MUF) but reduces the requirements for the cutting equipment, that is, the workpieces cutting accuracy, as well as the tolerances of the raw material. In addition, dies for open forging are tend to be more wear resistant.

## Forging equipment selection

Consider the approximate forging load value required for the axis-symmetric part forging for selection of the equipment:

,

where G – is the mass of steam hammer falling parts (a 1 ton approximately equals to 10 MN of press power), kg;

*D*fp – is the diameter of the circular forged piece in the parting line, m;

σB – is the ultimate tensile strength of a metal at the forging temperature, MPa.

Substituting a slightly increased diameter of the finished part *D*fp≈ 132.45 mm as the diameter of the forged piece and specifying the ultimate tensile strength of the steel 45 σB = 45 MPa by handbook, obtain the mass of steam hammer falling parts: *G* = 0.81 tons (the equivalent press load is approximately 8.1 MN).

Therefore, the steam hammer has selected for the finish forging operation. Despite some problems (small efficiency, vibration loads), this equipment has the following advantages: fast enough; allows to obtain a forged piece for a few strokes; applicable for large forged pieces; adjustable load and velocity of strokes.

## Selection of parting line for die tools

The parting line is decided to place at the top part of the forged piece corresponding to the maximum diameter in order to simplify the die tool design and increase its durability while accounting the selected position of forged piece on the die face. The parting line also passes over half of the hole height in the central part of the forged piece (for the MUF increasing purpose).

Thus, assuming the flat configuration of parting line for further simulation.

## Specification of paddings, allowances, and tolerances for the forged piece

The paddings, allowances, and tolerances for the forged pieces made of ferrous metals are specified in compliance with GOST 7505–89.

The initial index calculation parameters are determined on a basis of the steel 45 chemical composition and the mass of near-net-shape part *m* = 1.5 kg:

1. The approximate mass of the forged piece for the round part is *Kp*= 1.5...1.8 of the near-net-shape part mass:

*m1* ≈ *m* · *Kp* ≈ 1.5 · 1.7 = 2.55 kg.

1. The tolerance grade (according to the selected equipment – steam hammer) is T5.
2. The group of steel for steel 45 (in compliance with GOST 1050-88: 0.42–0.45% C, 0.17–0.37% Si, 0.5–0.8% Mn, no more than 0.035% P, no more than 0.04% S) with the carbon mass fraction of 0.435% and Total mass fraction of alloying elements up to 0.46% is M2.
3. The degree of complexity is determined by the ratio of forged part mass to the mass of the simplest geometric figure, which the forged part may be best inscribed in. The circumscribed cylinder mass for the specified part with overall dimensions (height *h* = 60 mm, diameter *d* = 125 mm) is determined using the following expression:

*m2* = π · *d*2 / 4 · *h* · *ρ* = 3.14 · 1252 / 4 · 60 · 7826 / 10003 = 5.76 kg,

where *ρ* = 7826 kg/m3 – is the density of steel.

The *m1* to *m2* ratio is 2.55/5.76 ≈ 0.44 and absence of thin elements of the part are stipulated the degree of complexity C2.

1. The surface configuration of the parting line is flat.

The initial index is equal to 14.

The values of allowances and dimension tolerances (Table 1) specified using the initial index while taking into account that the final dimension must consider the minimum fillet radii of the outside corners and may be rounded to the 0.5 mm.

Table 1

Determination of the dimensions and tolerances of forged piece

| The dimension for which the allowance is specified, mm | Basic allowance, mm | Additional allowance, mm | Final dimension, mm | Tolerance |
| --- | --- | --- | --- | --- |
| 60 | 4.6 | 1.0 | 66 | +2.1  –1.1 |
| ø125 | 4.6 | 0.6 | ø130.5 | +2.1  –1.1 |
| Ø50 | 4.0 | 0.6 | ø56 | +1.8  –1.0 |
| Ø60 | 4.0 | 0.6 | Ø65 | +1.8  –1.0 |
| 12 | 3.6 | 1.0 | 17 | +2.1  –1.1 |
| 14 | 3.3 | 1.0 | 18.5 | +2.1  –1.1 |
| Ø36 | 3.6 | 0.6 | Ø30 | +0.9  –1.6 |
| 30 | 3.6 | 1.0 | 25 | +0.9  –1.6 |
| Ø85 | 4.0 | 0.6 | Ø90 | +1.8  –1.0 |

Additional allowances (on the side) specified in Table 1 in compliance with GOST 7505 are considering:

1. The mismatch allowance on the parting line surface of 0.3 mm.

2. The flatness deviation of 0.5 mm.

The minimum fillet radius of the outside corners is 2.5 mm and assumed 2.5-2 mm. The forged piece internal corners radii are usually 2...4 times higher and assumed of 8+5 mm.

Drafts: The outside drafts should not exceed 7°, assumed of 7°±1°45'. The inside drafts – not more than 10°, assumed of 10°±2°30'.

The allowable residual flash size is 0.9 mm.

The mismatch allowance on the parting line surface is 0.7 mm.

The allowable flatness deviation is 1 mm.

The allowable burr height is 3 mm.

There is a hole in the near-net-shape part with the diameter *Dhole* = 36 mm and depth *hhole* = 66 mm. The piercing does not provide because the diameter of the center hole is ø36mm and more than 30 mm, but lower than hole depth. The designed blind mark will be removed during machining at drilling operation instead of the piercing operation.

The drawing of cold forged part has been designed as a result (Figure 2). The near-net-shape part contour has drawn with phantom lines. The central axial line and the bottom surface of the forged piece are selected as the machining datum axis and machining datum surface, respectively.

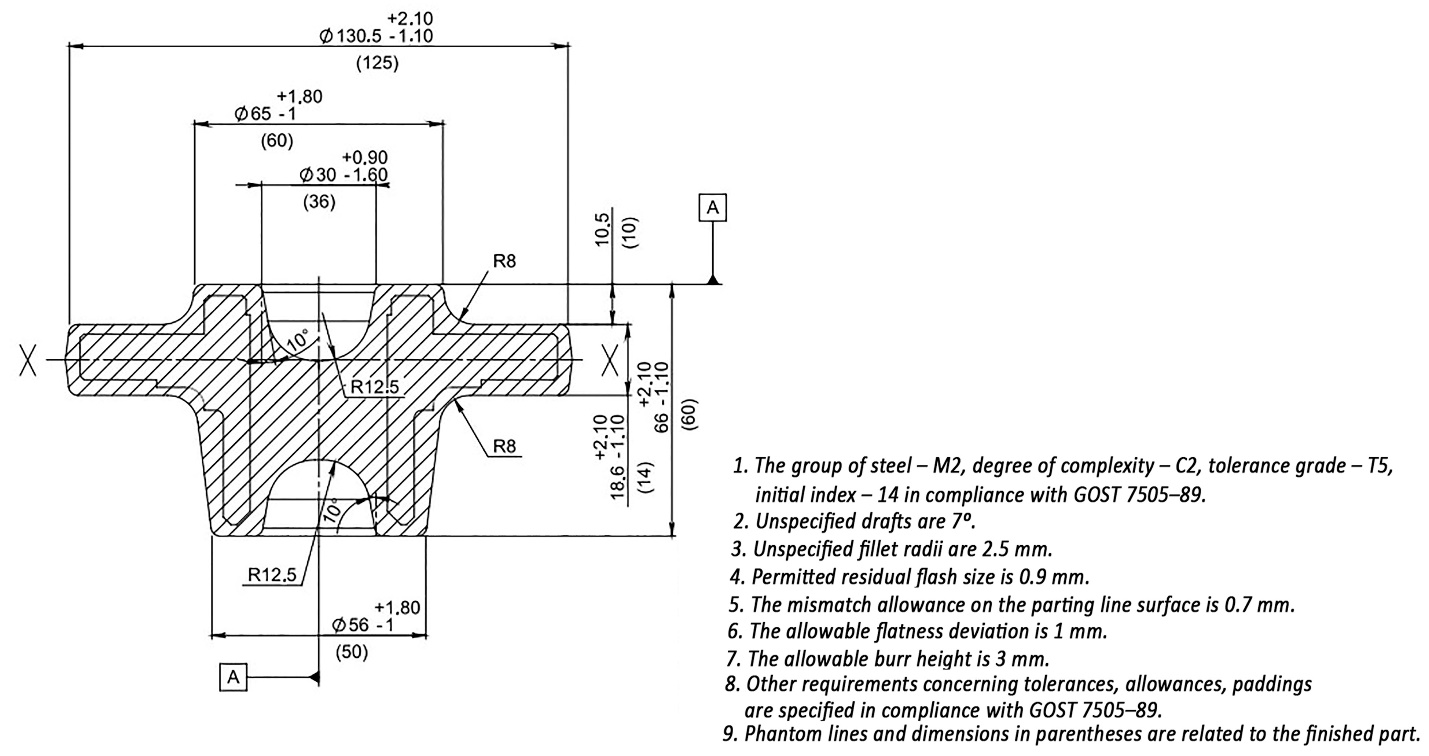


Figure 2. Drawing of cold forged part (dimensions of the near-net-shape part indicated in parentheses).

The forged piece volume was computed using the solid model in SolidWorks software package and became *V*fp = 380750.1 mm3, the mass *mfp* = 2.97975 kg (corresponding to the range of the precalculated forged piece mass for determining the initial index).

# Selection of forging operations

## Equipment selection

As already mentioned (see & 2.2), the steam hammer has chosen as the main equipment for finish-forging while considering of probable higher forging load required. The upsetting with expansion also performed on this equipment, and the preform impression is the upsetting area provided on the die surface for such purpose.

The upsetting is aimed to make the workpiece dimensions closer to the dimensions of forged part (thus reducing the work of deformation in the finish impression and increasing its tool life), increasing of forging reduction and mechanical properties while reducing anisotropy of properties in the axial and transversal directions, and, also, to align the end surfaces of the workpiece. Most of the scale appeared during workpiece heating is removed at upsetting.

The intermediate heating (and annealing) not scheduled between upsetting and forging operations: The equipment capacity is sufficient to maintain the required temperature in the workpiece providing the necessary plasticity of the metal. However, this assumption will be refined after analysis of simulation results in the Qform software.

The flash trimming operation is performed in a trimming die on the trimming press. However, the residual heat is used after the finish forging operation in order to reduce the required load and increase the die lifetime.

## Specification of the workpiece heating temperature and intermediate heating temperature

The main purpose of metal heating at forging is increasing of its plasticity, as well as reduction the deformation resistance, i.e. to reduce the deforming load required. In addition, mechanical properties of the forged piece may be improved by correct selection of heating mode and degree of deformation using the recrystallization curve.

A large number of factors must be considered when choosing a temperature interval: Effects of thermal expansion, phase (structural) transformations, appearing of temperature stresses, metal loss, etc. For this reason, the initial heating is selected on a basis of reference materials for the steel 45:

– the recommended initial forging temperature is 1250 °C

– the recommended final forging temperature is 750 °C

– the minimum final forging temperature (not lower) is 720 °C.

There should be no need of intermediate heating, however, if the metal chilling will appear according to the simulation results in the QForm software , it should be placed again in the oven while ensuring of high heating speed (in order to reduce metal wastes with scale and decarburization) to the specified initial forging temperature of 1250 °C.

It should be specially noted that not only heating, but cooling of forged piece is of great importance too. Cooling of forged pieces of steel 45 – in air.

## Selection of the heating equipment type

The heating method makes a direct impact on the production cost of forged piece, its quality, performance of the forging process and the die lifetime.

Electric heating is recommended for steel workpieces (resistance furnaces, salt-bath furnaces, induction heating), and the flame heating is commonly used for forging of large parts.

In this work is decided to apply the resistance furnace. A continuous furnace is selected considering the specified production volume (30,000 pcs). The advantages of this type of equipment are as follows: easy and accurate adjusting of heating mode, ensuring of non-oxidation heating, reduction of scale formation, a high level of hygiene and serviceability. Moreover, it complies with the Executive Order of Russian President Vladimir Putin which proclaimed the year 2017 as the Year of the environment in Russia.

# Design of working surfaces of die tools

## Gutter development

The amount of metal required for forging operation must consider the die wear, tolerances and allowances, etc. In addition, precision cutting of workpieces is low efficient and time-consuming operation. Therefore, in order to prevent incomplete filling of the die impression, the workpiece includes an extra volume of metal that is pushed into the gutter. It is reasonable to select the most common gutter type (Figure 3) for the developed production process.

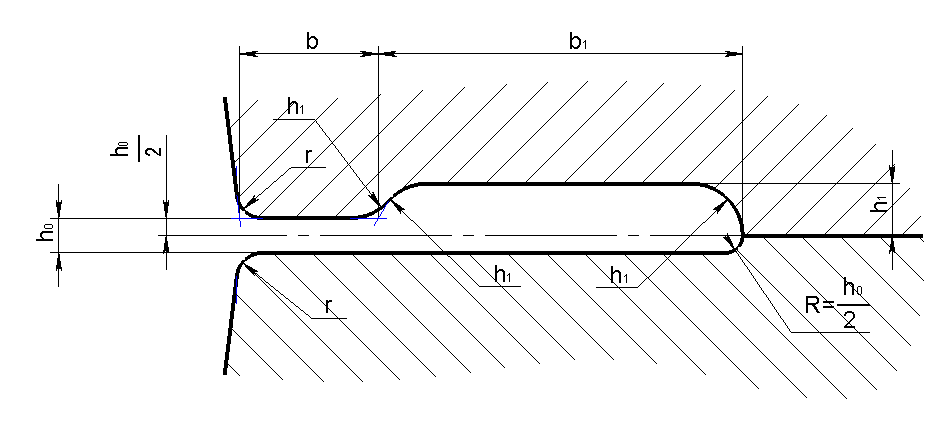


Figure 3. The selected gutter type

This gutter type ensures higher durability of the ridge (land) due to the upper mold is heating less than the lower one. Its dimensions are selected by reference data. They have specified in Table 2 for the developed forged piece 'Flange'.

Table 2

Gutter dimensions

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | *h0* | *h1* | *r* | *b* | *b1* |
| Dimension value, mm | 1.6 | 3.5 | 2 | 11 | 30 |

The gutter type may be changed, if necessary, according to the simulation results in the Qform software.

## Development of die impression surfaces

The hot forged part drawing, which considering the temperature linear shrinkage of the material at cooling, is used for design of die impressions. The thermal linear expansion coefficient (TLEC) for steel 45 at the final forging temperature of 750 °C is approximately equal to α ≈ 14.1 · 10-6 1/°C. Consequently, for thin and fast cooling elements of forged piece the shrinkage will be 1.011. At the same time, deformation heating, temperature gradient and temperature dependence of the TLEC should be considered, so the nominal forged piece dimensions will be increased in compliance with the recommendations on 1.015 (Figure 4). Simulation of the cooling operation in the Qform software will allow verifying of this solution.

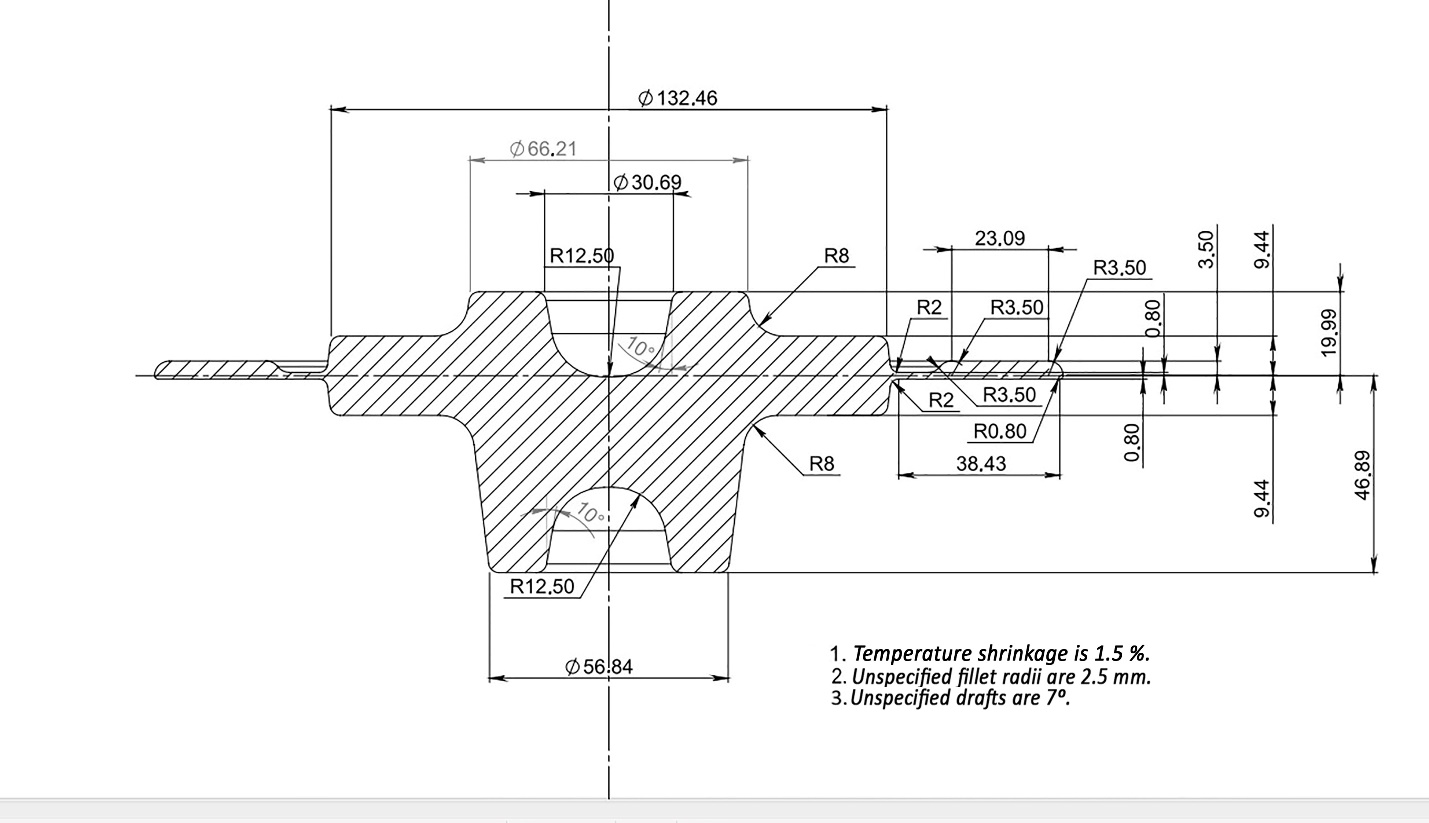
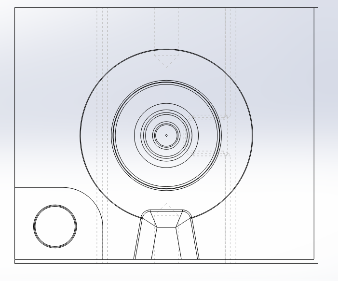


Figure 4. The sketch of hot forged part.

The height of extended part for the cavity forming for the preliminary die impression at upsetting with expansion is designed a slightly higher (5%) than for the finish die impression. The fillet radii are increased by 3 times. The upsetting area on the lower mold provided with a depression of diameter increased by 2% relative to the workpiece diameter and height of 2 mm for accurate workpiece positioning.

## Mutual alignment of die impressions

The forging is carried out in two passes, which are performed on the same die. The upsetting area displaced to the edge is provided for this purpose (Figure 5). The finish die impression is located in the center corresponding to the equipment axis. The load required for the plastic metal flow will be uniformly transmitted to the workpiece with such placement improving the forged piece quality and increasing the tool life.



2

1

Figure 5. Location of die impressions:

1 – is the upsetting area, 2 – is the finishing die impression.

# Workpiece design

## Calculation of the workpiece dimensions

The workpiece volume *V*wp is composed of the metal of forged piece, pierced web (if any) and flash. Additionally, the metal loss during heating is considered and approximately equal to 1% for the selected type of heating (electric) and grade of steel 45. Therefore, accounting the necessary gutter filling by 60% takes the following result:

*V*wp = (1 + 1%) · (*V*fp + *V*web + *V*flash) = (1 + 1%) · 446380.3 ≈ 450844.1 mm3.

The round steel bar is selected as a workpiece for the 'Flange' part. The ratio of the workpiece height *hwp* to its diameter *dwp* at upsetting should not exceed 2.7, but at the same time be large enough for structure formation of the forged piece. The *Hwp*/*Dwp* = 2 has choosen. Calculate the approximate value of the workpiece diameter using the previously determined volume:

65.7 mm.

Find the nearest appropriate diameter of round steel bar in compliance with GOST 2590-2006. *Dwp* = 67 mm. The workpiece height is calculated from the cylinder volume formula:

*Hwp* = *V*wp · 4 / ( π · *Dwp*2) = 450844.1 · 4 / ( 3.14 · 672) = 127.9 mm.

The workpiece mass is equal to the product of metal volume by the steel density:

*mwp* = *V*wp · *ρ* = 450844.1 · 7826/109 ≈ 3.53 kg.

The workpiece mass allows it to be moved by the worker using hand blacksmith tongs.

## Selection of blanking equipment

There is a large number of cut-to-length cutting techniques for a round steel bar, such as the bandsawing machine, gas-oxygen, plasma, and hydroabrasion cutting. Assume using of shear press or bandsawing machine based on the reference data for the found workpiece diameter of 67 mm. The shear press is a high-performance and inexpensive way of cropping, but the workpiece end surface is often ragged. Moreover, steel 45 requires additional heating (however, two-step heating before forging will reduce the probability of adverse effects of thermal stresses influence). Modern bandsawing machines are quite productive and allowing to obtain a plain end of the workpiece. Their drawback is the low saw lifetime, metal loss from the value of sawcut (reduction of the MUF), and, sometimes, an additional operation for handling of edges.

Taking into account that the first pass – upsetting with expansion requires a smooth end of the workpiece, the band-sawing machines have selected as the equipment.

## Calculation of dimension tolerances for the workpiece

Considering deviations from the workpiece dimensions is the most important for closed die forging. Because the flange part is stamped in an open stamp, which, when calculating the amount of the workpiece, takes into account the percentage of padding (and the possible wear of the stamp), The allowable deviations are selected from the table data in compliance with GOST 2590-2006 for the initial diameter tolerances and the cutting length by handbook [2]:

|  |  |  |
| --- | --- | --- |
| *Dwp* = 67 | +0.5  –1.1 | mm |
| *Hwp* = 127.9 | +0.8  –1.0 | mm |

The volume of metal with negative and positive tolerances is determined using the expression for the volume of cylinder: *Vnegative* = 432751.0 mm3, *Vpositive* = 460461.0 mm3.

It should be noted, that numeric evaluations were used for calculating the flash and forged piece volume in the past. At the present time, it is possible to measure body volumes by computer model effectively due to development of process engineering automation facilities, especially computer hardware and computer-aided design systems. For example, *Dwp* = 67 mm for the forged piece developed in SolidWorks (while considering the TLEC and metal loss ratio):

for filling 20% of the gutter: *Vwp2* = 417107.31 mm3, *Hwp2* = 119.5 mm;

for filling 80% of the gutter: *Vwp3* = 462475.75 mm3, *Hwp3* = 119.5 mm.

Filling 20% of the gutter is usually applied for small forged pieces, but the flash may not be sufficient for convenient extraction of the forged piece from die impression by blacksmith tongs in the case of high die tool wear. On the contrary, 80% may be excessive due to the metal flow behavior (without considering of chamfering on the butt ends after cutting).

The volume of selected workpiece with *Hwp* = 127.9 mm, calculated with negative tolerances, and the volume calculated with the positive tolerances are within the specified boundaries, so, the initial workpiece parameters are specified correctly.

## Calculation of the metal utilization factor (for the assumed workpiece and forged piece)

The material utilization factor is equal to the ratio of the metal quantity (volume or mass) of the near-net-shape part to the amount of metal used for its production. Therefore, MUF for designed forged piece of mass *mfp* = 2.97975 kg:

*MUFfp* = *m* / *mfp* = 1.5 / 2.97975 = 50.3 %.

The MUF value obtained from the workpiece mass mwp is used for reflecting of the (economic) production efficiency:

*MUF* = *m* / *mwp* = 1.5 / 3.53 = 42.5 %.

The values found confirm the proper use of open-die forging with flash for the 'Flange' part.

# Selection of the auxiliary and finishing operations

Besides the main operations reviewed (cutting a round steel bar on cut-to-length workpieces, heating, forging, flash trimming), the production technology includes:

1. In-process control, which includes visual and instrumental research methods (check dimensions of workpiece and forged piece, hardness, defects, die wear degree, etc.).
2. Heat treatment intended to reduce residual stresses and improve mechanical properties of forged piece – quenching 900–920 °C, tempering 620–650 °C in air.
3. Purging the forged piece from residual lubrication used at the die forging and surface contamination after heat treatment – air blasting in the sandblast machine.
4. In the case of superficial defects (within tolerance), the finish grinding must be performed.
5. Labeling, lubrication and packaging for storage or transportation to a mechanical workshop for further processing.

All operations with specified process parameters indicated in the routing map (see Appendix to the report).

# Analysis of simulation results

The simulation of production technology operations has been performed in the QForm software developed by QuantorForm Ltd., with the parameters specified in Table 3.

Table 3

Steps, parameters, and simulation results in the Qform software

|  |  |  |
| --- | --- | --- |
| Operation description | Initial position | Simulation results |
| Cutting on cut-to-length workpieces | Not simulated due to the necessity to perform quick calculations (as 2D axis-symmetric) | |
| Heating of the workpiece: The ambient temperature is 1280 ºC, holding time is 26.8 minutes (1608 s), the linear expansion coefficient of 14.1·10-6 1/ºC.  (Simplified for 2D: A workpiece is placed on the end surface instead of laying | The workpiece of ½D = 33.5 mm, H = 127.9 mm, T0 = 20 ºC | A relatively uniform heating T1= 1250±10 °C |
| Upsetting: the 2 ton steam hammer. The workpiece volume has reduced by 1% to reflect the metal loss. Cooling time before the 1st stroke is 10 s in air, 5 s in the die tool  For subsequent blows – 2 s in the die tool. The power of the 1st stroke is 50 %, the other – 100 %. |  | Maximum load: 0.984 MN |
| Finish forging: the 2 ton steam hammer. Cooling time before the 1st stroke is 10 s in air, 5 s in the die tool  For subsequent blows – 2 s in the die tool. The power of the 1st stroke is 50 %, the other – 100 %. |  | Number of strokes: 3  Maximum load: 27.9 MN |
| Flash trimming: 6.3 MN press. Mass and gravity have not considered |  | Flash trimming load: 0.06 MN |
| Web piercing | Not simulated |  |
| Forged part cooling | 2D | The dimensions are corresponding to the drawing of cold forged part; |

The QForm software makes it easy to create a copy of the calculated process and replace the previously specified geometry. So, the operations listed have used for analysis of various forging options, including changing the workpiece volume, impression shapes of die tool, and so on.

## Adequate assessment of the finite element mesh and calculation scheme

Assuming simplifications used for the simulation (solving the problem in the two-dimensional axis-symmetric formulation), the resulting model characterizes the investigated operations adequately. The auto-generated finite element mesh has the correct distribution: smaller elements (Figure 6) are used in the elevated deformation zones and near the angles of forged piece.

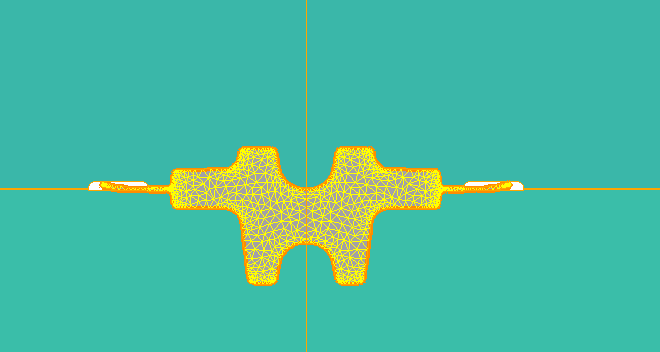


Figure 6. Finite-element mesh of the model at finish forging.

Consequently, the simulation results accurately show the progress of the forging process.

## Checking process for compliance with the forging temperature interval

At the end of the finish forging operation, the maximum temperature is equal to 1300 ° C, minimum = 1000 °C (Figure 7).

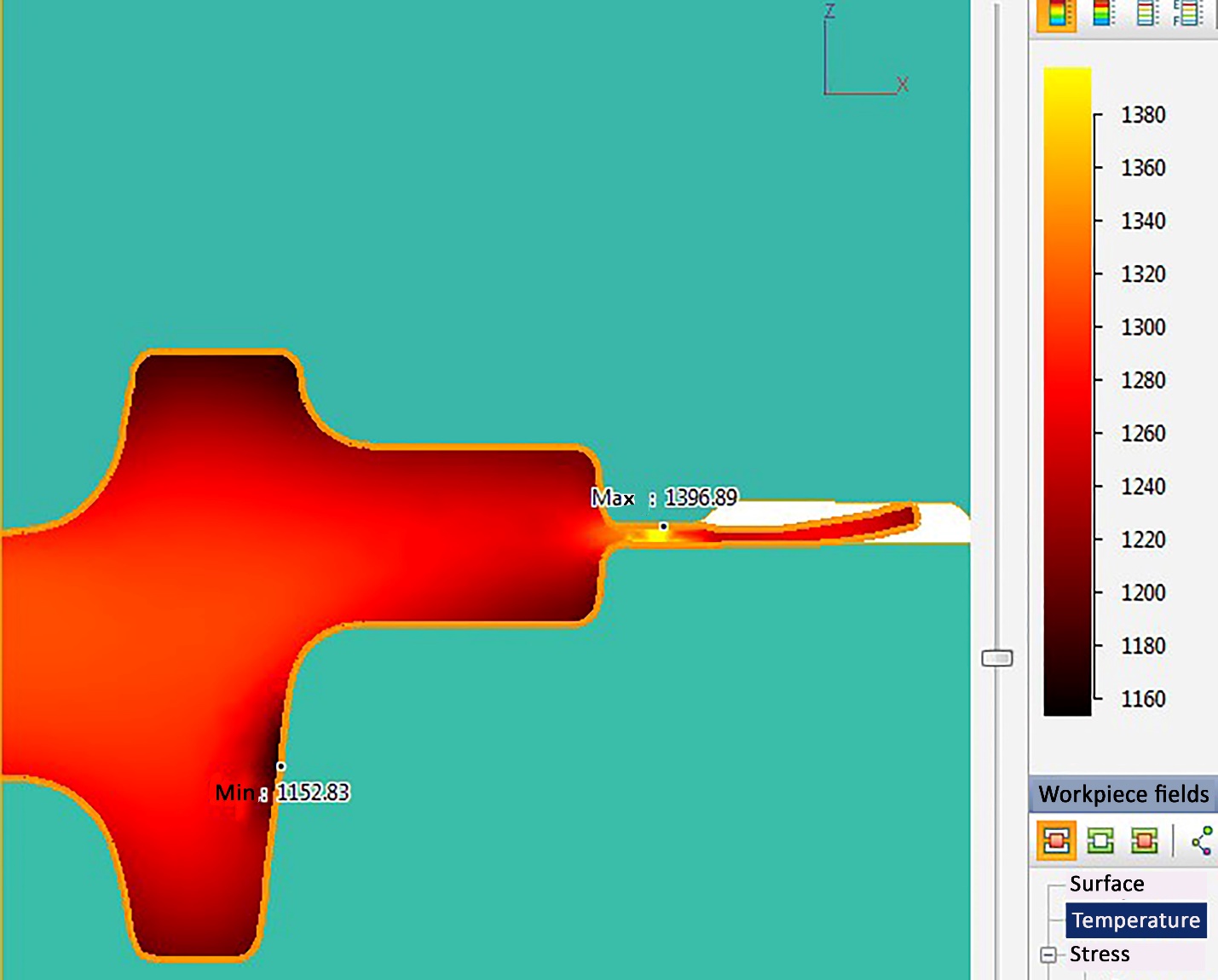


Figure 7. Temperature distribution at the end of forging operation.

Temperatures in the forged piece, obtained during simulation, are not into the recommended forging temperature interval of 1250–750 °C. Changing of the heating mode for this reason is not necessary.

The minimum temperature in the forged piece is slightly below the acceptable level at the recommended interval, so heating of die tools up to 250 °C or speeding up the equipment by reducing of waiting time before deformation may be proposed. It is also acceptable to select a lubricant with a lower heat transfer coefficient.

The maximum temperature in the forged piece is slightly higher than the acceptable level at the recommended interval, so decreasing of workpiece heating temperature by 50÷100 °C may be proposed (however, it will increase the required load) or reduce the equipment speed by increasing the waiting time before deformation. However, high temperature areas mostly localized near the gutter land and should not have a significant impact on the forged piece quality.

## Verification of the conformity of forging load and energy parameters with performance values of specified equipment

The maximum loads of the forging process are typical for the last stage of filling the die impression with the metal (Figure 8).

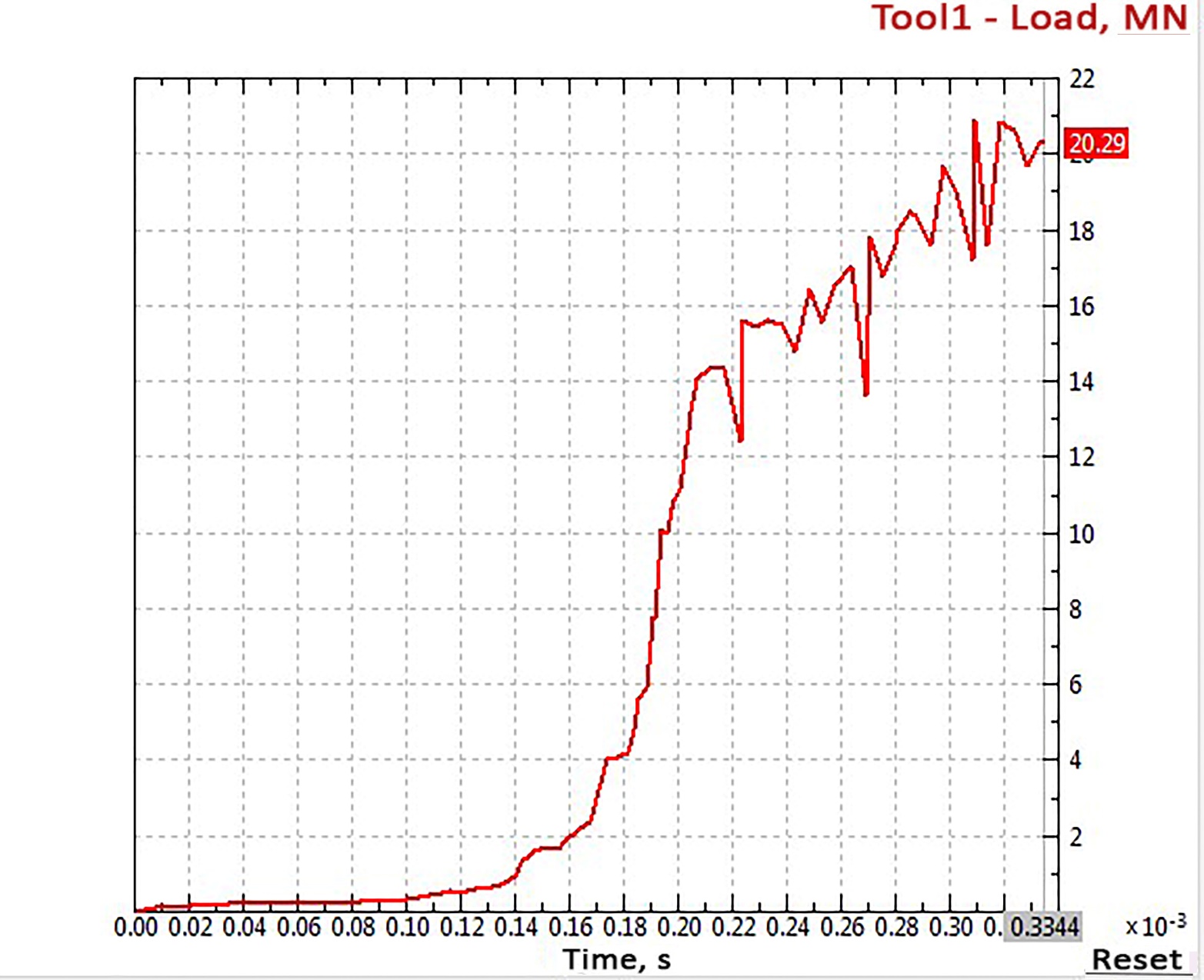


Figure 8. The required forging load

The simulation results has shown clearly that the necessary forging load is 27.9 MN is generally complies with the selected equipment.

## Die impression filling analysis

Considering the die impression filling dynamics, it should be noted that the metal flow is homogeneous, there is no risk of jams in the early upsetting stages (Figure 9).

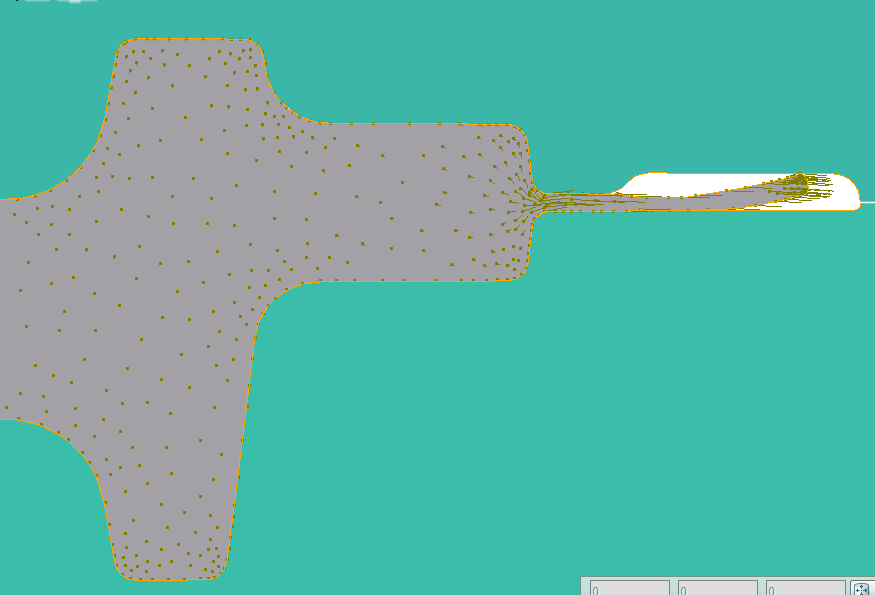


Figure 9. Metal flow direction at die impression filling.

All the upper and lower die impression cavities intended for the metal of forged piece are filled completely (Figure 10).

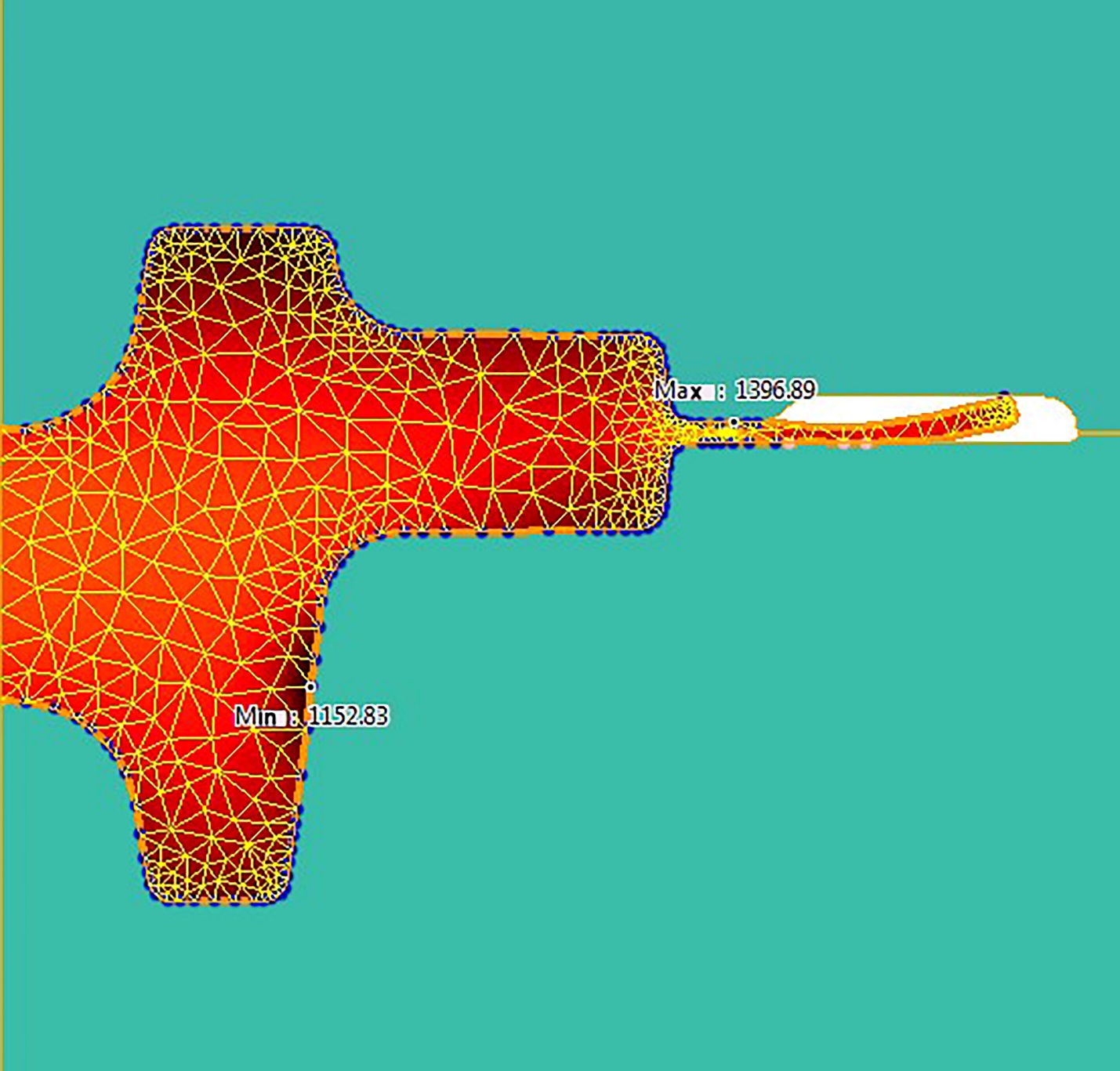


Figure 10. Complete filling of the die impression at the end of the forging (blue points are indicating contacts of finite element nodes with the surface of die tool).

## Check for complete filling of the land and no gutter overflow

The simulation has demonstrated that the workpiece volume is calculated correctly. The gutter pinches the metal preventing its free flow out at the end of forging, when the back pressure is required to fill the remaining cavities of die impression. The flash size of required length (Figure 11).

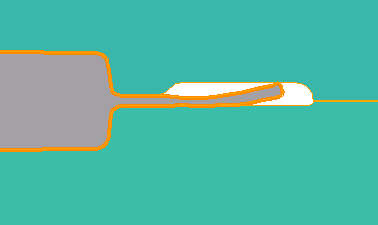


Figure 11. Gutter filling with metal.

## Check for defects of forged piece (laps, flow-through defects)

There are no defects in the forged piece and it is a fair assumption to say that very unlikely to occur due to the die impression filling behavior (Figure 12).

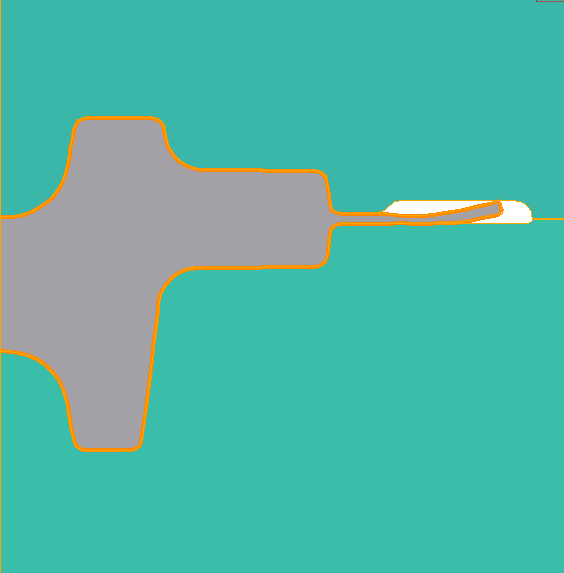


Figure 12. Show laps and flow-through defects mode (at end of forging operation).

## The forged piece (and part) fibrous structure assessment

It is known that internal radii should be 2...4 times more than outside radius, unless appearing of metal jams or fibers cross-cutting. The simulation has shown that the structure and final properties of the forged piece are likely to be less uniform. However, a significant cross-cutting of fibers occurs only in the gutter area, which is typical for open die forging. It is assumed that implementation of closed-die forging or addition new passes will improve the structure of forged piece

## Analysis of the die stress-strain state, detection of possible destruction locations

The temperature fields and the concentration of stresses calculated in the QForm for the developed die tools make it possible to estimate a potential tool life (Figure 13).

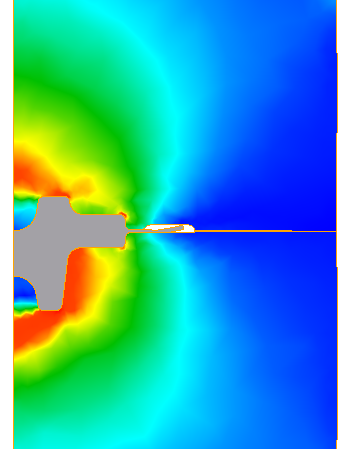
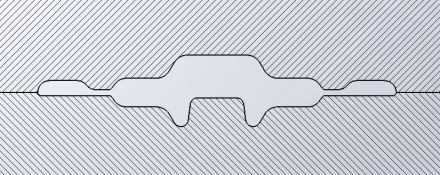


Figure 13. Stresses in the die tool (at the end of forging operation).

The most dangerous are stresses caused by the high pressures combined with the temperatures (Figure 14).



Unrecoverable (plastic) deformation

Mechanical fatigue

Thermal fatigue

Wear (friction wear)



Figure14. Probable place of defects in the tool.

The fillet radii may be increased to remove the tool life (if necessary), although this will reduce the metal utilization factor (MUF). It is possible to change also the applied lubrication or the die tooling material.

# Optimization of the forging process variants

## Simulation-based optimization of forged piece shape

The simulation demonstrated a high quality filling of the die impression, there are no defects, and, consequently, there is no reason to increase the outside corners radii. Conversely, the absence of hardly filled thin edges makes it possible to reduce the drafts slightly.

## Simulation-based optimization of forging temperature conditions

It is essential to keep the recommended forging temperature interval – the top and bottom boundaries, for the forging and bulk metal forming operations. The QForm simulation has shown that at the end of the forging a metal temperature corresponding to the contour of the near-net-shape part remains high enough, so that the initial heating temperature may be reduced slightly. However, this mearure will increase the required forging load or necessary hammer strokes number.

## Simulation-based optimization of the workpiece dimensions

The workpiece dimensions have chosen correctly, the gutter filled correctly: pinching takes place in the final stages of the forging. However, if you have a high-quality raw material, you may consider a one pass isothermal forging while using the initial workpiece with the diameter corresponding to the diameter after upsetting.

## Simulation-based optimization of die working surfaces

It is recommended to use smoother transitions between the forged piece elements for reducing the wear of die tool parts: This is achieved by increasing the drafts and fillet radii. In addition, it is possible to simplify the forged piece geometry by closing of some cavities with a padding. However, these actions will reduce MUF and increase the labour intensity of further machining. Another way to increase the wear resistance of die tools is offsetting the partition line (or web) or adding an intermediate forging operation.

# Conclusions on the work

The production technology has been developed for the 'Flange part' made of steel 45 and the die tooling designed.

Finite element simulation of the forging process in the QForm software has been performed. The part has been obtained of the specified shape and dimensions with no defects using the operations proposed. The power and load parameters match the equipment specified in the task.

The options for optimizing the workpiece, die impression shape, and the process parameters have suggested on the basis of simulation results.

It should be noted that the application of the QForm software allowed automate the development of forging technology, predict and correct possible design inaccuracies. At the present time, it is no longer theoretical calculations, namely the modelling results are accepted for reliable data.

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