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

**CODE** 125

University „St. Kiril and Metodius“ - Skopje

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# 1. Task

The company taken an order to produce 30,000 "Coupling" parts. It is necessary to develop the technological process for manufacturing of forgings for further machining taking into account the drawing of the minimum allowances for machining. The following equipment is available:

* hydraulic press (10 MN, 10 mm/c)
* steam-air hammer (2 t, 50 kJ).

Task notes

Create a report containing the process description and results of performing task including calculations and justification of the proposed technology, applications and drawings in a text file. Simulation should be done in QForm software for estimation and verification of the developed technology.

Quality, reasonability, correctness and chosen approaches of technology problem solving influence on the final mark, taking into account the following criteria:

The final evaluation of the work will be judged taking into account quality, correctness and applied approaches in acceptance of solutions, including the following criteria:

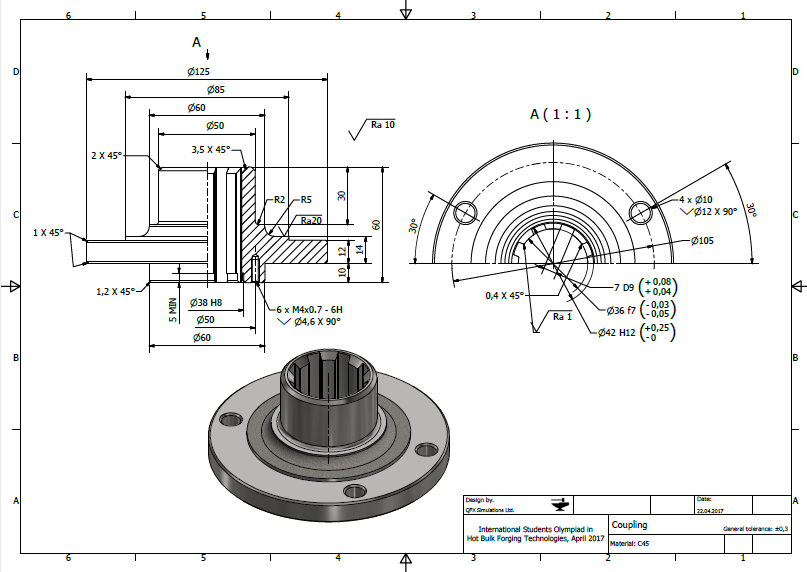
• equipment selection (evaluation of efficiency and productivity, force and energy parameters)

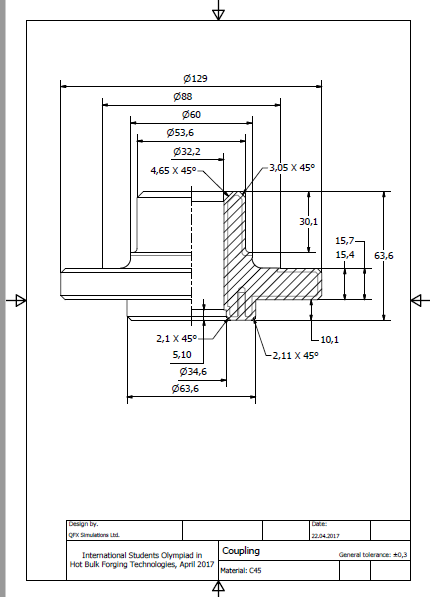
• selection of forging steps (evaluation of material consumption, deformation load, etc.)

• development of die forming cavities (taking into account die cavity filling, lack of stamping defects, etc.)

You have 6 hours to design the technology, to simulate it and to create a report using a text editor.

At the end of the work you have to create an archive (use special number provided by committee) which include a report and a QForm simulation file (without data folder) of a single final process version. The report title and QForm files have to contain your special number too. Do not specify your name and surname.





# 2. Designing the forged part

The forged part design is developed by using the part drawing and following the guidelines found in the EN DIN 10243-1 standard. This standard covers hot forgings made from carbon and alloy steels with a mass up to 250 kg.

## 2.1. Category of steel used

The type of steel used takes account of the fact that steels of high carbon and high alloy content are more difficult to deform and cause higher die wear than steels with lower carbon content and lower alloying elements.

The category of steel used is determined as being one of the following:

* **group M1:** Steel with carbon content not more than 0,65% **and** total of specified alloying elements (Mn, Ni, Cr, Mo, V, W) not more than 5% by mass;
* **group M2:** Steel with carbon content above 0,65% **or** total of specified alloying elements (Mn, Ni, Cr, Mo, V, W) above 5% by mass;

To determine the category in which a steel belongs, the maximum permitted content of the elements in the steel specification shall be used.

Table 2.1: Chemical composition [%] of steel C45 (1.0503): DIN EN 10084-2008

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Grade :** | | C45 | | | | | | |
| **Number:** | | 1.0503 | | | | | | |
| **Classification:** | | Non-alloy quality steel | | | | | | |
| **Standard:** | | EN 10250-2: 2000 Open steel die forgings for general engineering purposes. Non-alloy quality and special steels. | | | | | | |
| **C** | **Si** | | **Mn** | **Ni** | **P** | **S** | **Cr** | **Mo** |
| **0.43 - 0.5** | **max   0.4** | | **0.5 – 0.8** | **max 0.4** | **max   0.045** | **max   0.045** | **max 0.4** | **max 0.1** |

;

The steel C45 has a carbon mass fraction of up to 0,5% and a total mass fraction of its alloying elements of 2,19%. This places the steel in the **group** **M1.**

## 2.2. Shape complexity factor

The shape complexity factor takes account of the fact that in forging thin sections and branched components, as compared to components having simple compact shapes, larger dimensional variations occur which are attributable to different rates of shrinkage, higher shaping forces and higher rates of die wear.

The shape complexity factor of a forging is the ratio of the mass of the forging to the mass of the enveloping shape necessary to accommodate the maximum dimensions of the forging.

The resulting shape complexity factor is determined as falling within one of the following categories:

* **S4:** up to and including 0,16;
* **S3:** above 0,16 up to and including 0,32;
* **S2:** above 0,32 up to and including 0,632;
* **S1:** above 0,63 up to and including 1;

The parts mass and volume can be determined by using any CAD software while using the density of the material in question.

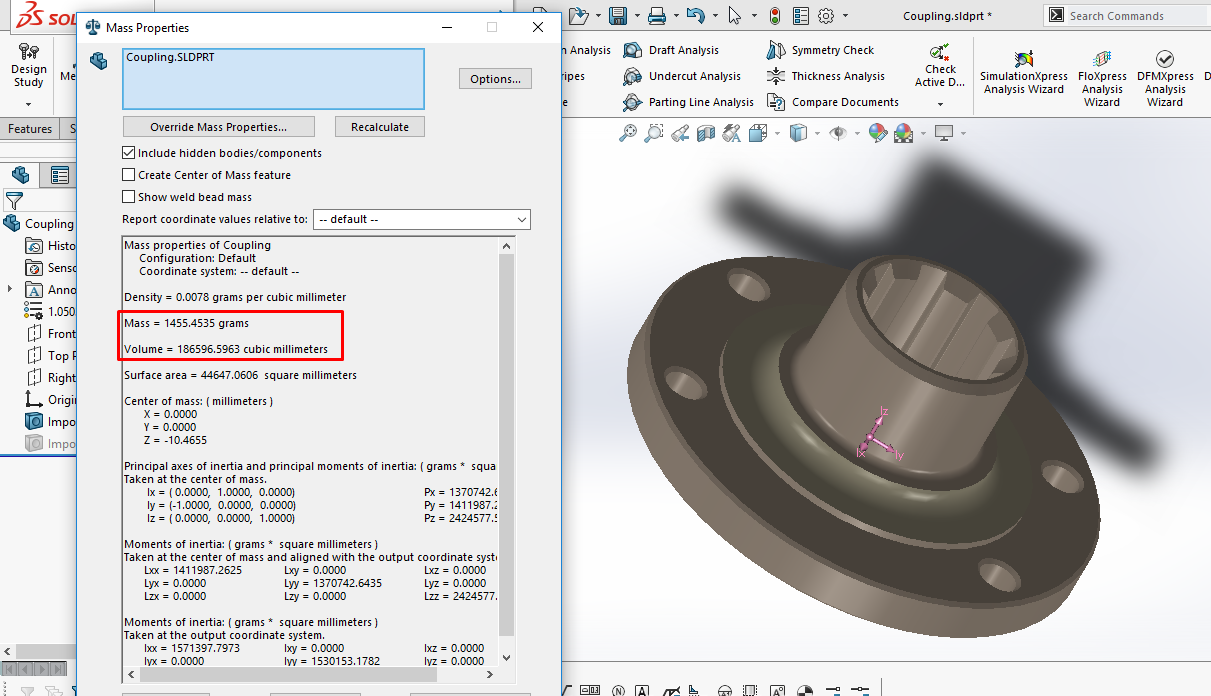


Figure 2.1: Mass properties for the final part – Solidworks

The enveloping shape of a circular forging is the circumscribing cylinder the volume of which is calculated by increasing the maximal width and height of the final part by 5% to accommodate the increased size of the forging.

The complexity factor falls in the **S2 category**.

It is important to emphasize that the initial complexity factor is an estimated value due to the estimation of the forgings and enveloping shapes mass. The estimated degree of complexity should be refined after calculating the exact envelopes and forging mass.

## 2.3. Parting line configuration

The part has a plain parting line configuration located at the half point of the thickness at the largest diameter (as shown in figure 2).

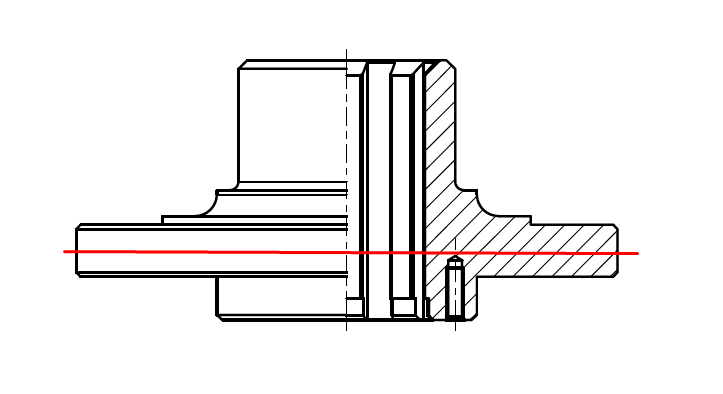


Figure 2.2: Parting line

## 2.4. Forging equipment selection

In order to begin the forging design, we must first select a forging machine by doing a control calculation to determine the plausibility of the technological process on the available equipment by estimating the needed machine force.

* for power-drop steam hammers:
* for mechanical presses:

The steel C45 can be classified in the third type according to table 2. From there we select the values for for the forging hammers and mechanical presses for the calculations.

Table 2.2: Steel strength in the final forging stages

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Type of steel** | **Forging hammers** | **Mechanical presses** | **Horizontal forging machines** |
| 1. | Carbon steel with carbon content up to 0,25 % | 5,5 | 6 | 7 |
| 2. | Carbon steel with carbon content above 0,25 %, or Alloyed steel with carbon content up to 0,25 % and alloying element content up to 5% | 6 | 6,5 | 8 |
| 3. | Alloyed steel with carbon content above 0,25 % and alloying element content up to 5% | 6,5 | 7 | 9 |
| 4. | Alloyed steel with alloying element content above 5% | 7,5 | 8 | 10 |
| 5. | Alloy tool steel | 9 - 10 | 10 - 12 | 12 - 14 |

Since the estimated value for the needed force on the mechanical press is the limit for our equipment, the power-drop steam hammer is selected as the forging machine used to manufacture the forging of the gear. All the tolerances and machining allowances will be selected to suit the forging process on steam hammers.

## 2.5. Defining the forged part dimensions

All of the tolerances and machining allowances for the forged part were selected from the tables 1 to 6 from the standard DIN EN 10243-1. The standard identifies two grades of tolerances, as follows:

* **forging grade F** with tolerances providing an adequate standard of accuracy for the majority of applications and capable of being complied with by commonly used forging equipment and production methods;
* **forging grade E** providing closer tolerances to assist in accommodating those instances in which the normal manufacturing standards are inadequate;

The forging grades „E“ and „F“ were allocated to the measures, depending on the particular surface roughness and tolerances designated in the part drawing.

The standard also identifies four major types of dimensions and several minor ones and classifies them in 4 groups. The major dimension and their relationship to the forging direction and die line are given in Table 3.

Table 2.3: Relationship between types of dimensions and die line

|  |  |  |
| --- | --- | --- |
| **Dimension** | **Forging direction** | **Die line** |
| Length (b)  Width (b) |  | one side |
| Height (h) | // |
| Thickness (a) | // | across |

All of the allocated allowances and tolerance grades for the inner and outer forging dimensions are given in table 4. Finally, the resultant dimensions are modified by a factor that takes into account the thermal expansion while heating. The outer dimensions are increased and the inner ones are decreased by a specific amount that corresponds to the forging temperature. This way we get the correct hot forging part design with measurements ready for creating the die geometry.

- thermal expansion coefficient for steel alloys at forging

temperatures of ~1200 °C;

Table 2.4: Tolerances and machining allowances for the forged part

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Tolerances and permissible variations according to DIN EN 10243-1** | | | | | | | | |
|  | | **Part dimension** | **Forging grade** | | **Tolerance** | | **Total forging dimension** | **Final die dimension with temperature scaling** |
| **Diameter (b)** | **Outer** | 125 | F | |  | |  |  |
| 85 | F | |  | |  |  |
| 60 | F | |  | |  |  |
| 50 | F | |  | |  |  |
| **Inner** | 36 | E | |  | |  |  |
| **Thickness (a)** | | 60 | F | |  | |  |  |
| 12 | F | |  | |  |  |
| **Height (h)** | | 10 | F | |  | |  |  |
| **Other tolerances:** | | | | | | | | |
| **Type of dimensions** | | | | | | **Tolerances and permissible variations** | | |
| Missmatch allowance | | | | | | Mismatch 0,5  Max. permissible tolerances 1,6 | | |
| Residual flash (+)  Trimmed flat (-) | | | | | | 0,5 | | |
| Ejector marks tolerance | | | | | | / | | |
| Straightness and flatness | | | | | | 0,8 | | |
| Centre-to-centre dimensions | | | | | | / | | |
| Trimming burr | | | | Height | |  | | |
| Width | |  | | |
| Eccentricity for deep holes | | | | | | / | | |

## 2.6. Forging draft angles

Draft is an angle allowance added to surfaces parallel to the direction of die closure to facilitate release of the part from the die after forging. In general, draft allowances on inside surfaces are greater than those on outside surfaces, because of the tendency of the part to shrink onto projections in the die as cooling takes place.

For power drop steam hammers the chosen normative draft angles are as follows:

## 2.7. Forging fillet radii

All edges and corners in the part must have added fillets. These fillets are necessary to aid material flow and ensure good die filling. In addition, sharp corners in dies can lead to premature die failure due to fracture as a result of associated high stress concentrations. In general, larger radii are recommended for the more difficult-to-forge materials.

The outer radii are selected depending on the mass of the forging and the largest depth of the die impression that is calculated according to the position of the parting line.

The inner radii are calculated using the formula:

## 2.8. Defining the position, shape and dimensions of the barrier plates for all through holes in the forged part

In the forging process, holes are not punched through because this would make the ejection of the part more difficult. This is why the dies are separated by a barrier plate in each hole.

The thickness of the plate is calculated using the following equation:

The filet radii for the plate also have to be calculated. Hence, we use the equation:

The type of the plate depends on the size of the forging part, the diameter and the height of the hole. To determine the type we need to check the following condition:

The condition requires the use of a Type I plate with a shape shown in Figure 3.

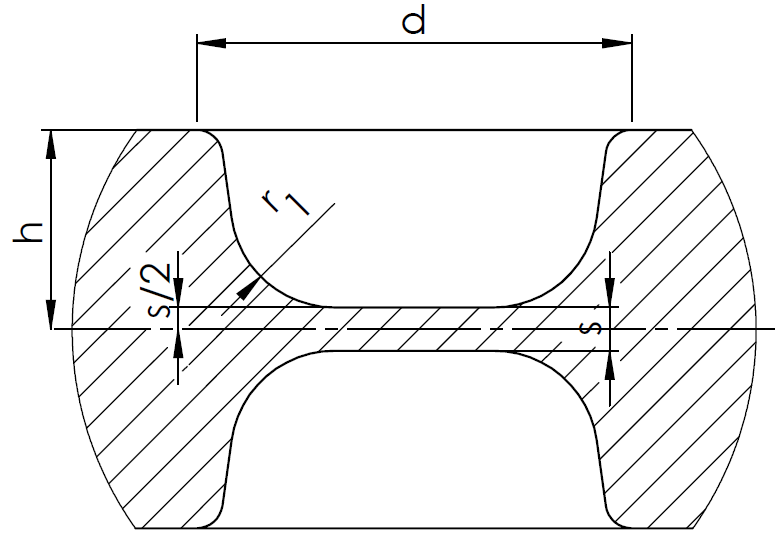


Figure 2.3: Barrier plate – type I

## 2.9. Control check for the forging mass and the complexity factor S

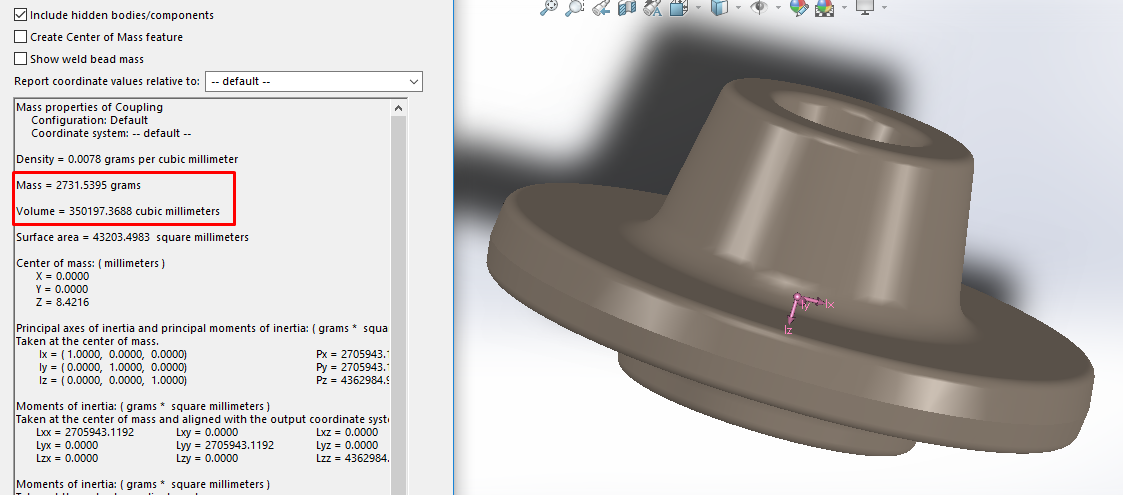


Figure 2.4: Mass properties for the developed forging part – Solidworks

The complexity factor falls in the **S2 category,** same as the initially calculated value. Since the mass is within the previously selected range and the refined complexity factor matches the initial calculation, the added allowances are considered correct.

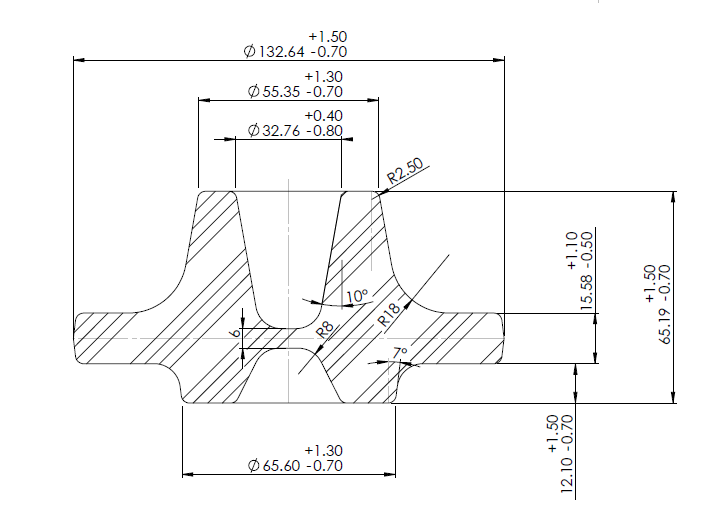


Figure 2.5: Drawing of the forged part

# 3. Determining the flash land geometry

The flash produced during closed-die forging is scrap material and may in many cases have a volume that is more than 50% of the final part volume. The amount of flash produced increases with the complexity of the part. However, the production of flash is a necessary part of the process, and its control is essential to ensure good die filling.

The choice of the appropriate width and thickness of the flash land is an important part of the forging process design. If the geometry is wrong, the dies may not fill completely or the forging loads may become excessive. In addition, the projected area of the flash in the flash lands is usually included in the total projected area of the part for estimation of the forging loads required and therefore is a determining factor in equipment selection for processing.

In order for vertical flow to occur in the die, the resistance to flow in the flash gap must be higher than that required for vertical flow in the die. The material must not flow into the flash gap until the die cavity is completely filled. This resistance to flow in the flash gap depends upon the ratio of flash land width to flash land height.

The flash land height can be calculated approximately using the following expression:

The flash land width is calculated with the help of a coefficient that takes into account the way the die is filled during the forging process:

According to the calculated values for the bridge height and the coefficient we choose the nearest standard flash land size. All relevant dimensions are given in Table 5 and Figure 6.

Table 3.1: Standard flash land and gutter dimensions

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |  |  |
| 1.6 | 3,5 | 1 | 8 | 22 | 102 | 3,5 | 0,8 |

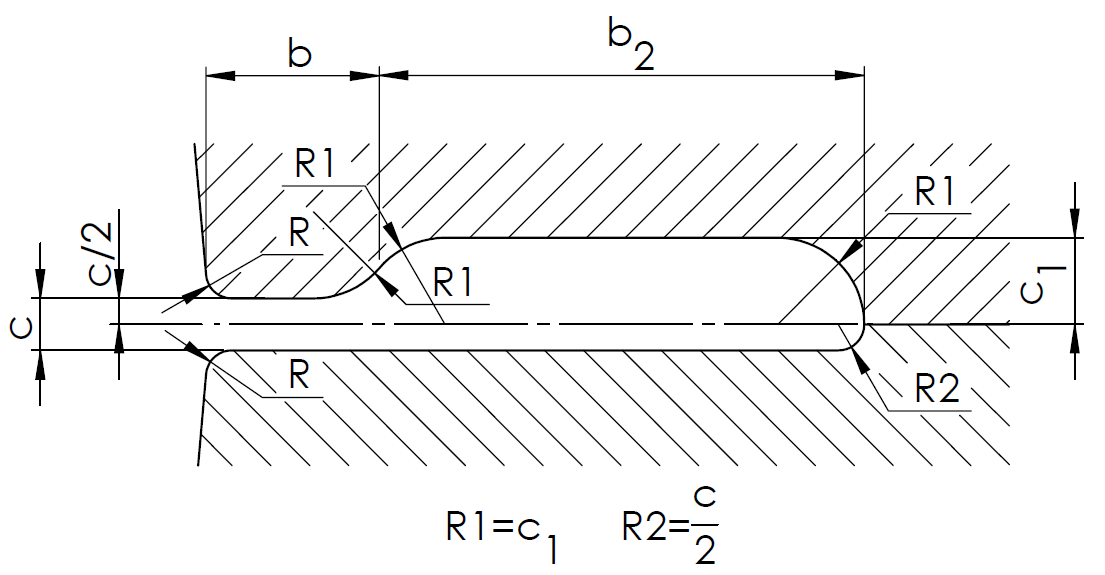


Figure 3.1: Flash land, shape and dimensions

Finally we need to determine the flash volume in order to be able to calculate the dimensions of the initial workpiece. The flash volume is calculated by the following expression: meter

# 4. Determining the initial workpiece dimensions

The volume of the workpiece is the sum of the forging and the flash volume, while taking into account the scale losses that occur during heat treatment processes. Oxide scales discolour the metal surface and hinder subsequent finishing operations and therefore need to be removed from the heated stock, either before or during forging operations.

Due to the fact that scale loss cannot be included in the simulation, for the purpose of this report, the scale loss coefficient is not taken into account .

Round parts are forged from cylindrical billets and before the dimensions are calculated we need to determine the relation between the height and the diameter of the workpiece.

This relation is in the range . If then the shearing of the billet to size is more difficult and is accompanied by the forming of big burr formations. For ratios of there is a risk of buckling.

The billets dimensions are determined by the volume and the ratio . The estimated diameter is calculated as follows:

The standard dimensions for cylindrical billets are found in Kraut's Mechanical Engineering Handbook:

The billets height is calculated using the expression:

The billet for the gear forging has the following dimensions:

# 5. Determining the die block dimensions

The dimensions selected for the die blocks depend on the depth of the cavity. The minimal thickness and height for each block (Table 7) were selected according to the recommendations in Table 6. The size of the block

Table 5.1: Recommended minimum die block dimensions

|  |  |  |
| --- | --- | --- |
| **Cavity depth**  **h [mm]** | **Minimum thickness**  **a [mm]** | **Minimum die block height**  **H [mm]** |
| 6 | 12 | 100 |
| 10 | 20 | 100 |
| 16 | 32 | 125 |
| 25 | 40 | 160 |
| 40 | 56 | 200 |
| 63 | 80 | 250 |
| 100 | 110 | 315 |
| 125 | 130 | 355 |
| 160 | 160 | 400 |

Table 5.2: Selected die block dimensions

|  |  |  |  |
| --- | --- | --- | --- |
|  | **h [mm]** | **a [mm]** | **H [mm]** |
| **Upper block** | 37 | 56 | 200 |
| **Lower block** | 28 | 40 | 160 |

# 6. Production phases

1. Shearing the initial workpiece with a diameter of and height of
2. Heating up the workpiece to the forging temperature of
3. Descaling – removing the oxidized layers from the heated stock.
4. Upsetting the workpiece to a diameter of and height . The upsetting is carried out on a hydraulic press (10 MN, 10 mm/c)
5. Finish forging done on a power-drop steam hammer to the shape and dimensions given in Figure 2.5
6. Flash removal using a trimming die.
7. Punching the barrier plates for all through holes (operation 4 and 5 can be done simultaneously if an appropriate cutting/punching tool is used)

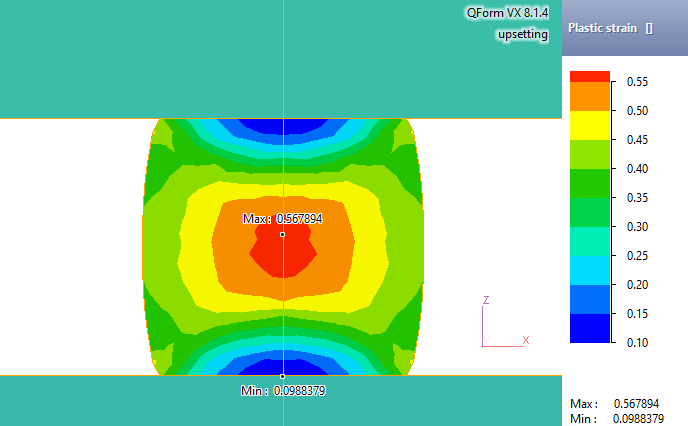
# 7. Simulation results

Table 7.1: Simulation parameters

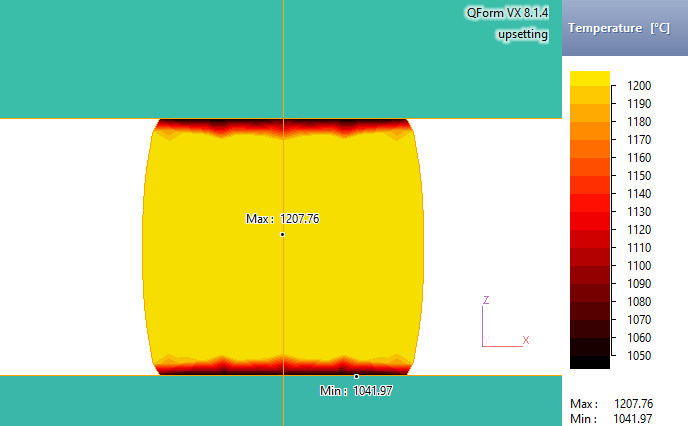
|  |  |  |  |
| --- | --- | --- | --- |
|  | | **General simulation parameters** | |
| **Process** | Process type | General forming with thermal processes | |
| Problem type | 2D, axisymmetric | |
| **Workpiece parameters** | Material | C45 | |
| Temperature | 1200˚C | |
| **Tool parameters** | Coupled deformation | No | |
| Heat exchange with the workpiece | Simple | |
| Drive | upsetting | Tool 1 – hydraulic press (10 MN, 10 mm/c)  Tool 2 – Fixed drive +OZ |
| Finish forging | Tool 1- steam-air hammer (2 t, 50 kJ).  Tool 2 – Fixed drive +OZ |
| Lubricant | Graphite + Water | |
| Material | D2 AISI | |
| Temperature | 200˚C | |
| **Boundary conditions** | Environment | Air 20˚C | |
|  | | **Operation specific parameters** | |
| **Operation 1:**  **Upsetting** | Number of blows | 1 | |
| Cooling in air | 2 sec on transfer only | |
| Cooling in tool | 1 sec after each blow | |
| Stop condition | Distance: 75 mm between Tool 1 and Tool 2 | |
| **Operation 2:**  **Finish die forging** | Number of blows | 2 | |
| Cooling in air | 2 sec on transfer only | |
| Cooling in tool | 1 sec after each blow | |
| Stop condition | Distance: 0 mm between Tool 1 and Tool 2 | |
| Tools boundary conditions | Tool 1 – Rigid fixing  Tool 2 – Rigid fixing | |

## 7.1. Process operations

* Upsetting

Figure 7.1: Зони на деформација

* Збивањето се одвива со хидраулична преса (10 MN, 10 mm/c). На сликата се приметуваат класичните зони на деформација.

Figure 7.2: Температура при збивање

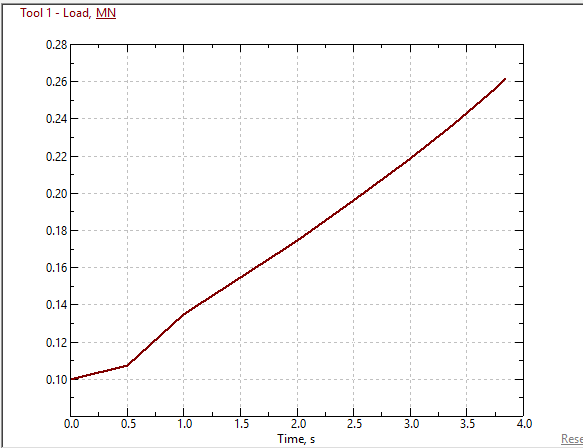


Figure 7.3: Сила при збивање

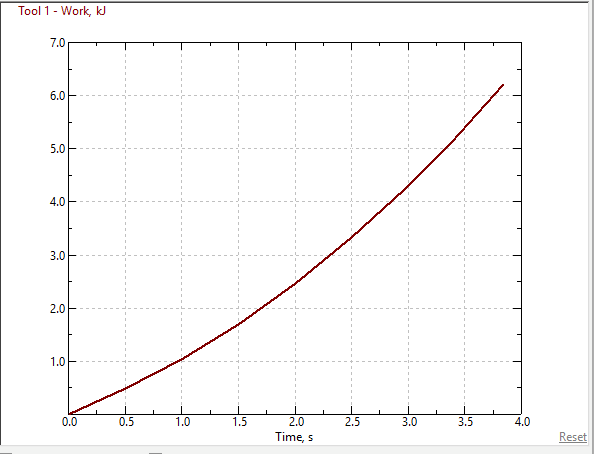


Figure 7.4: Работа при збивање

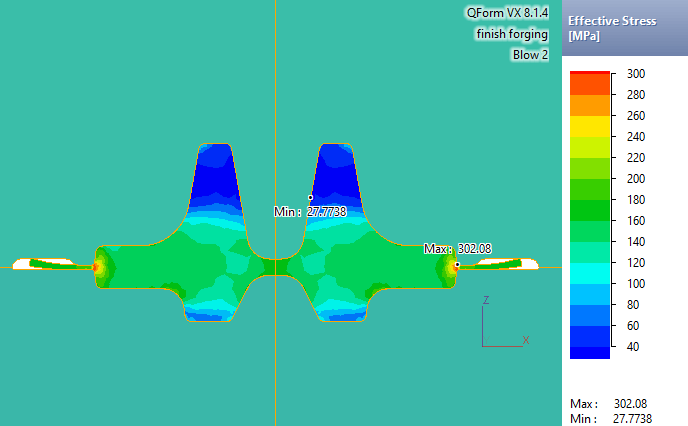
* Finish die forging

Figure 7.5: Напрегање во во последната операција.

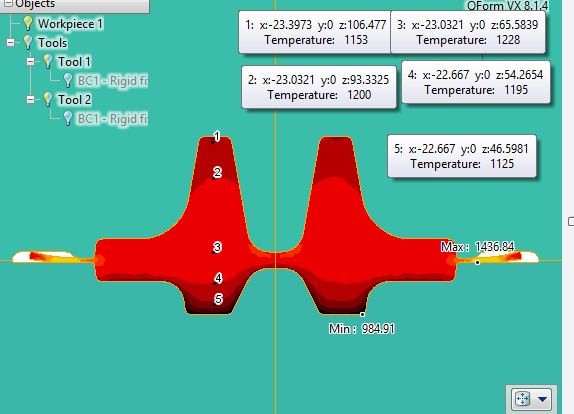


Figure 7.6: Температури во последната операција.

Гравурата целосно се исполнува на вториот удар, а максималното напрегање се јавува при влезот на венецот каде што се и очекува.

* Температурните разлики се помалку од 10% што ги задоволуваат условите.

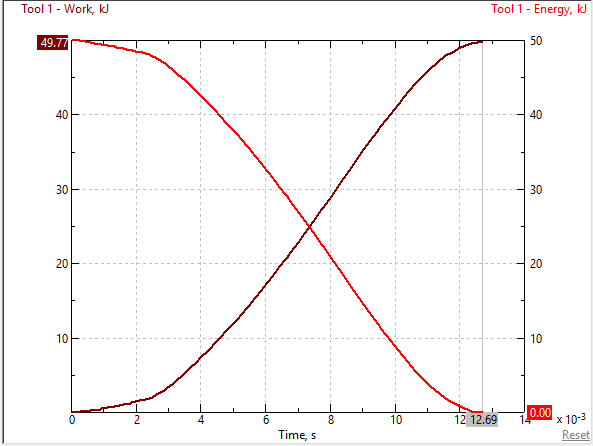


Figure 7.7: Сила во првиот удар во втората операција.

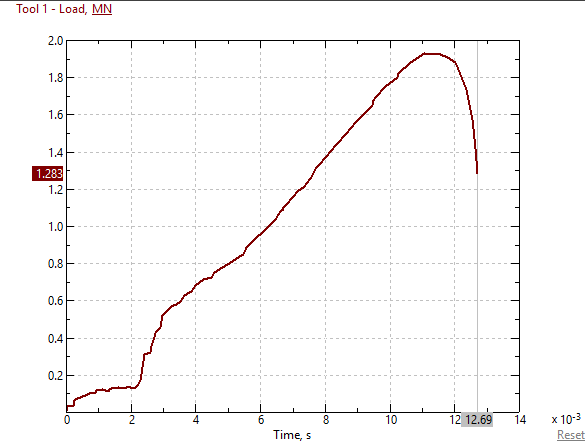


Figure 7.8: Работа и енергија во првиот удар на втората операција.

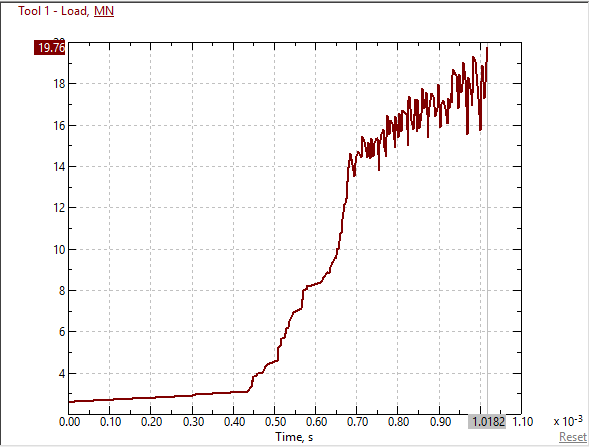


Figure 7.9: Сила во вториот удар во втората операција.

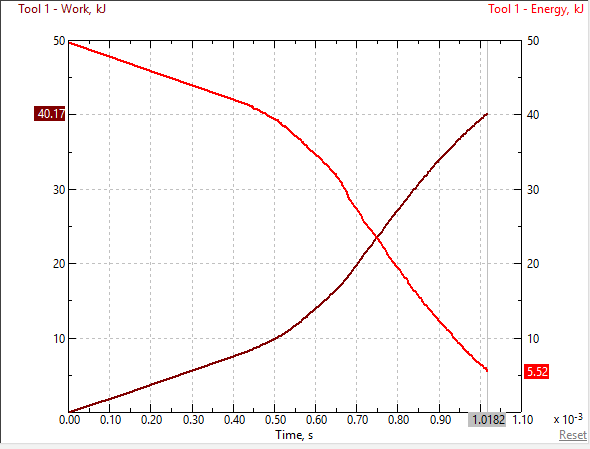
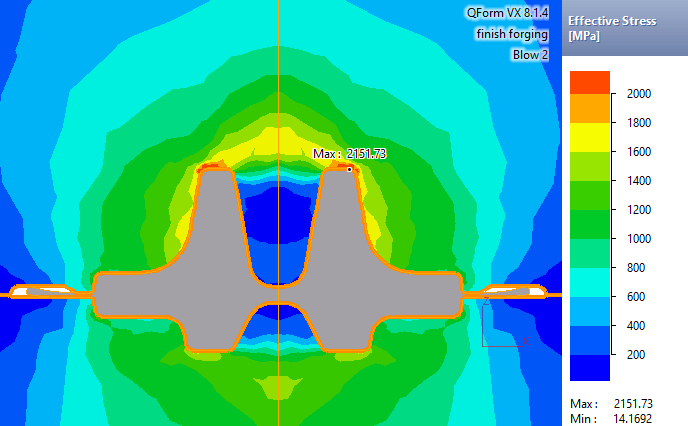


Figure 7.10: Енергија и работа во вториот удар во втората операција.

## 7.2. Анализа на алат

The die block size is chosen according to the recommendations shown in the previous chapters. The size of the die blocks is irrelevant if we only want to analyze the forming process, but it’s important when doing a stress analysis of the tooling elements.

The simulation of the tools is done at the moment when the highest load appears during the forging process and this is determined by analyzing the loading graphs. This corresponds with the load of 21.14 MN that appears at 1.0.19 seconds into the final blow (159th increment) of the final forging operation (Figure ).

Figure 7.2.1: Напрегање во алатот.

* Максималното напрегање го надминува максималното дозволено напрегање на материјалот, но тоа може да се оптимира со промена на заоблувањата.

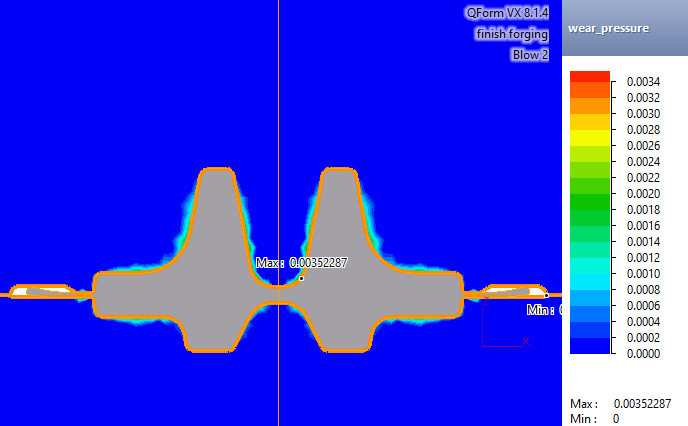


Figure 7.2.2: Абење во алатот.

* Горниот дел на алотот притиска со поголема површина па затоа е и повеќе изложен на абење. Абењата се многу мали.

# Заклучок

Гравурата целосно се исполнува со два удари на чеканот. Течењето се одвива нормално.

Во венецот може да се намали материјалот со што ќе се намали должината на почетното парче.

Дизајнот може да се подобри со со зголемување на надворешните агли со што ќе се намали максималното напрегање во алатот.