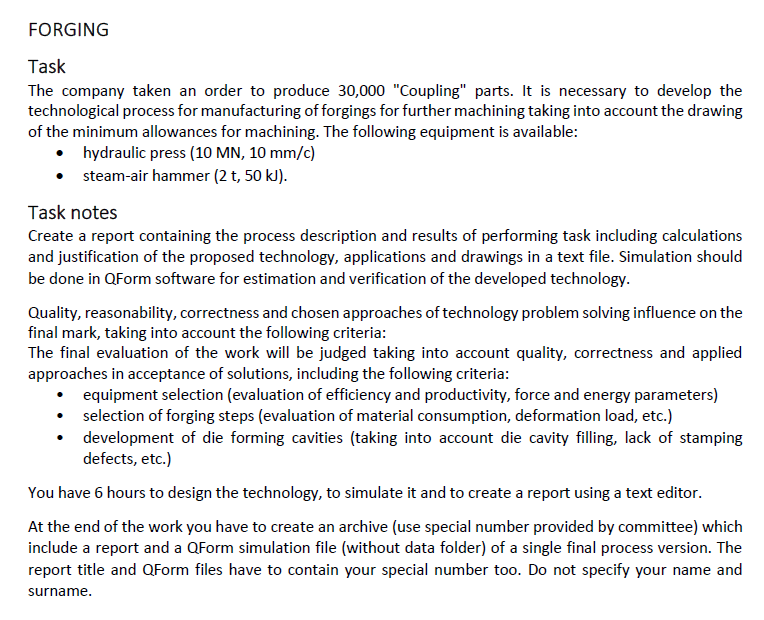
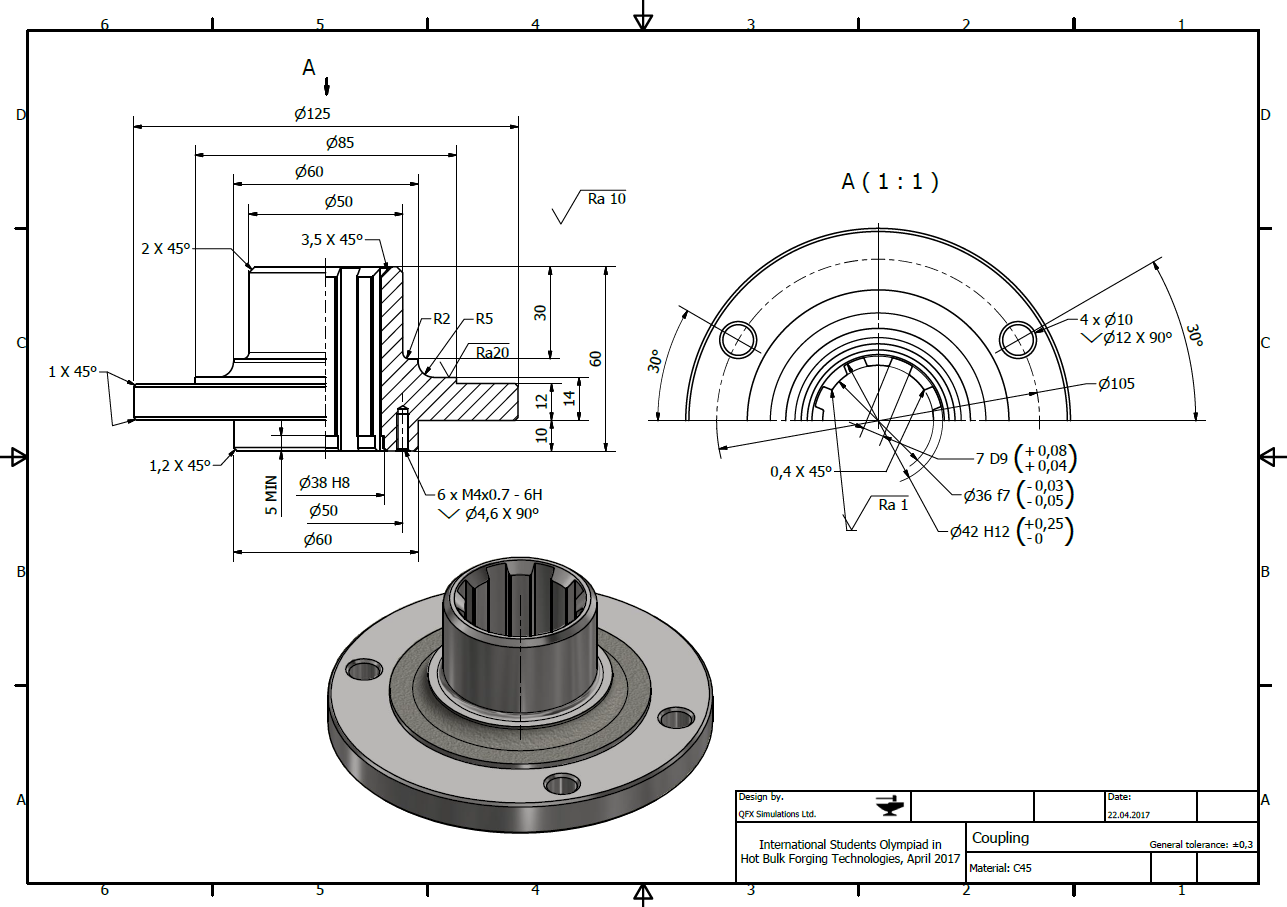
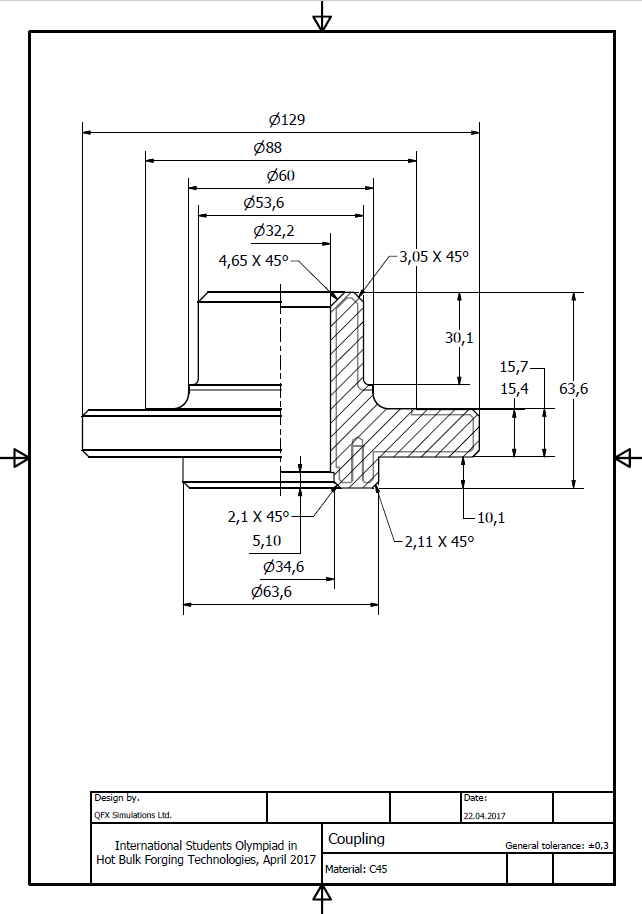
**The International Students Olympiad in Hot Bulk Forging Technologies**

*CODE 201*

**

**

**

# *1. Development of forged part drawing.*

The forged part drawing is developed by the detail drawing according to the DIN EN 10243-1 “Steel die forgings - Tolerances on dimensions - Part 1: Drop and vertical press forgings”.

The standard refers to steel forgings with weight up to 400 kg and determined a maximum value of the additives for machining, tolerances on dimensions and etc. The development of specific technology and drawing of forging allows reduction of these values in order to save material, increasing accuracy and increase the durability of tooling. Depending on the purpose and operating conditions of the part, forgings are divided into categories in terms of: ***accuracy of manufacturing (tolerance grade), material (group of steel), degree of complexity and configuration on the parting line of dies.***

* 1. **Tolerance grade**

The tolerance grade can be chosen from 2 possible grades: **First Class** and **Second Class**. First Class tolerance grade is used for forgings with increased accuracy Second Class tolerance grade is used for forgings with normal accuracy.

For the given task the used tolerance grade is **Second Class**.

**1.2 Group of steel**

The group of steel should be determined with the help of the following table *(table 1)*:

*Table 1. Determination of steel group*

|  |  |  |
| --- | --- | --- |
| Group of steel | Carbon mass fraction, % | Total mass fraction of alloying elements, % |
| **M1** | Up to and including 0.45 | Up to 2.0 |
| **M2** | More than 0.45 | More than 2.0 |

The group of steel assumed for steel C45 (*C*≤ 0.17-0.4%, *Si*≤ 0.17 - 0.4%, *Mn* ≤ 0.5-0.8%) is ***M1*** with carbon mass fraction up to 0.45% and the total mass fraction of alloying elements less than 2%.

**1.3 Degree of Complexity**

**The degree of complexity** (***C1, C2, C3*** and ***C4***) is determined according to the formula:

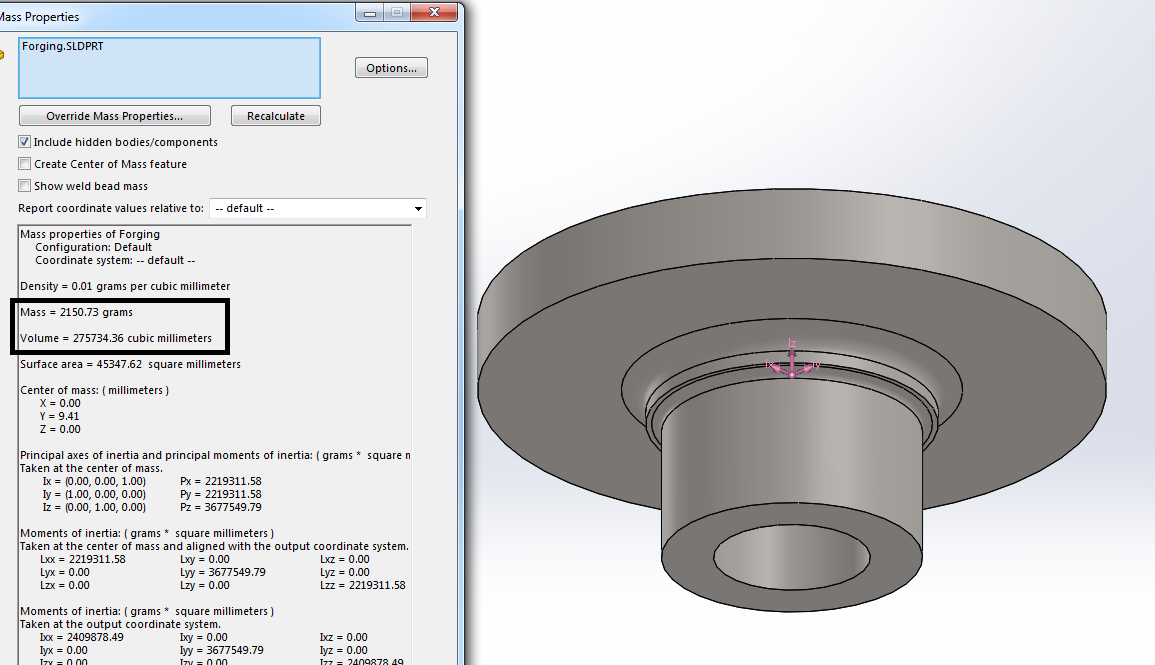
,

where M*F.P.*– is the forged part mass, M*S.F.*– is the mass of the simplest solid geometric figure, in which the forged part may be inscribed in. In this case, a figure the forged part inscribed in is a cylinder, but the mass of forged part is not determined. Therefore, we determine the estimated degree of the forged part’s complexity *CEST* according to the formula *[2].*

where M*F.P.C*. – is the calculated mass of the forged part (estimated); M*F.C.* – is the calculated mass of the figure (cylinder) (estimated).

where *MD*– is the mass of detail, *KC*– is the design coefficient that is assumed depending on the configuration of forged part. For round forgings such as gears, hubs and flanges the coefficient KC varies in the interval 1,5÷1,8.

The mass of detail may be determined by using of SolidWorks software package while choosing the steel C45 (defining its density fig.2).



*fig 2. Determination of part’s volume (VD) and mass (MD)*

The part drawing determines that we have a round forging. Therefore, I choose Kc = 1,5.

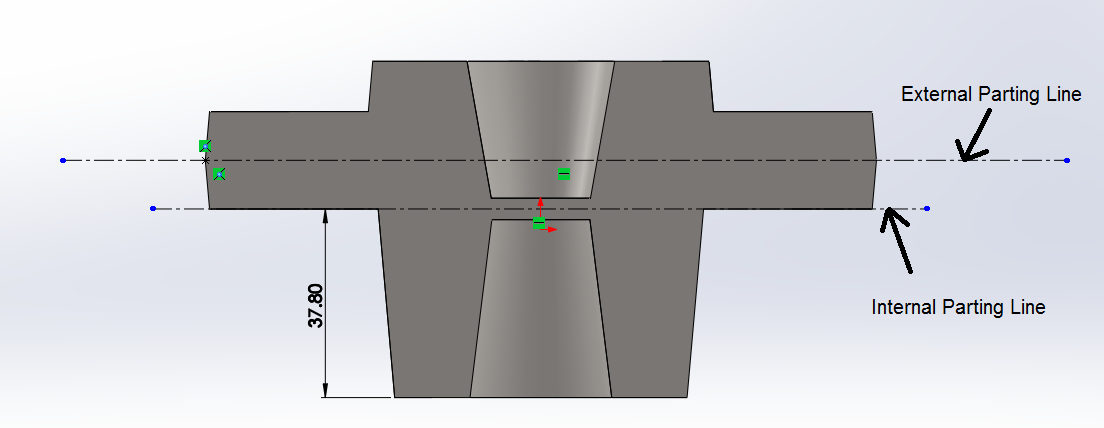
The MF.C. is determined on a basis of increasing the overall linear dimensions of the simplest figure in which the part can be inscribed by 1,05 times.

In the case of a solid cylinder MF.C. is calculated with the help of the following formula:

The value of the CEST is corresponding to the C2 degree of complexity [0.32÷0.63]. The estimated degree of complexity should be refined after calculating envelopes of the metal.

A drawing of forging is developed in the following order :  
- Configuration on the parting line of dies;  
- Selection of machining datum surface and determination of the additives for machining;  
- Determination of the drafts for die forging (external and internal);   
- Determination of the fillet radii for die forging (external and internal);   
- Determination of the position, shape and dimensions of the barrier metal layer for the openings in the forged part;  
- Determination of dimensional tolerances for the forged part;

**1.4. Configuration on the parting line of dies**



External - from the half thickness of the biggest diameter

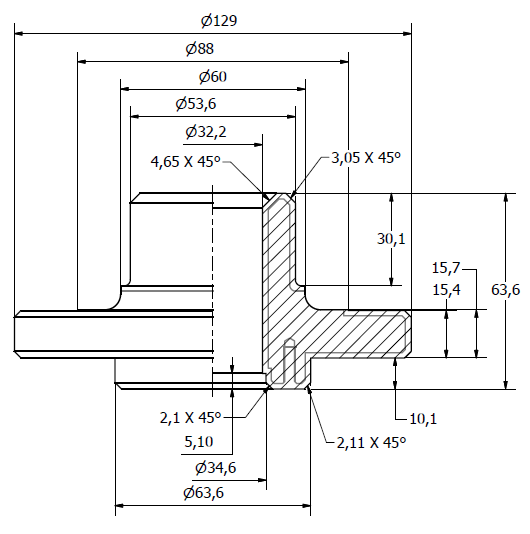
Internal - from 0.56 of the height from the bottom

**1.5. Selection of machining datum surface and determination of the additives for machining.**

The selection of machining datum surface is made from the drawing of the part (fig.1).

According to the standard the additives are determined depending on the weight of the forging, tolerance grade (II class), the group of steel (M2), the degree of complexity (C2) of forging, size and roughness of the plane, which concerns the additive.

For this gear we use table 2 to determinate the additives for machining.



*Fig.1Drawing of the part*

*Table 2. Additives for machining*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Mass of the Forged Part [Kg] | Size of the forged part [mm] | | | | | |
| Under 50 | 50-120 | 120-180 | 180-260 | 260-360 | 360-500 |
| Up to 0,25 | 1,1 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 |
| 0,25 – 0,40 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 |
| 0,40 – 0,63 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 | 1,8 |
| 0,63 – 1,0 | 1,4 | 1,5 | 1,6 | 1,7 | 1,8 | 1,9 |
| 1,0 – 1,6 | 1,5 | 1,6 | 1,7 | 1,8 | 1,9 | 2,0 |
| 1,6 – 2,5 | 1,6 | 1,7 | 1,8 | 1,9 | 2,1 | 2,1 |
| 2,5 – 4,0 | 1,7 | 1,8 | 1,9 | 2,1 | 2,2 | 2,3 |
| 4,0 – 6,3 | 1,9 | 2,0 | 2,1 | 2,3 | 2,4 | 2,5 |
| 6,3 – 10,0 | 2,1 | 2,2 | 2,3 | 2,5 | 2,6 | 2,7 |
| 10,0 – 16,0 | 2,3 | 2,4 | 2,5 | 2,7 | 2,8 | 2,9 |
| 16,0 – 25,0 | 2,5 | 2,6 | 2,7 | 2,9 | 3,0 | 3,1 |
| 25,0 – 40,0 | 2,7 | 2,8 | 2,9 | 3,1 | 3,2 | 3,3 |
| 40,0 – 63,0 | 2,9 | 3,0 | 3,1 | 3,3 | 3,4 | 3,5 |
| 63,0 – 100,0 | 3,2 | 3,3 | 3,4 | 3,6 | 3,7 | 3,8 |

The largest dimension of the forging will be more than 120 mm so we chose the additives for machining to be 1,9 mm. The smallest dimension of the forging is more than 50 mm so the additives for machining from 50 to 120 mm is 1.9 mm.

Some of the additives are rounded up to 2.5 mm in order of the fillets radii not “eating up” material from the part. Also some of them are 2.5 mm in order for the die drafts to remove some of the coupling steps for easier forging.

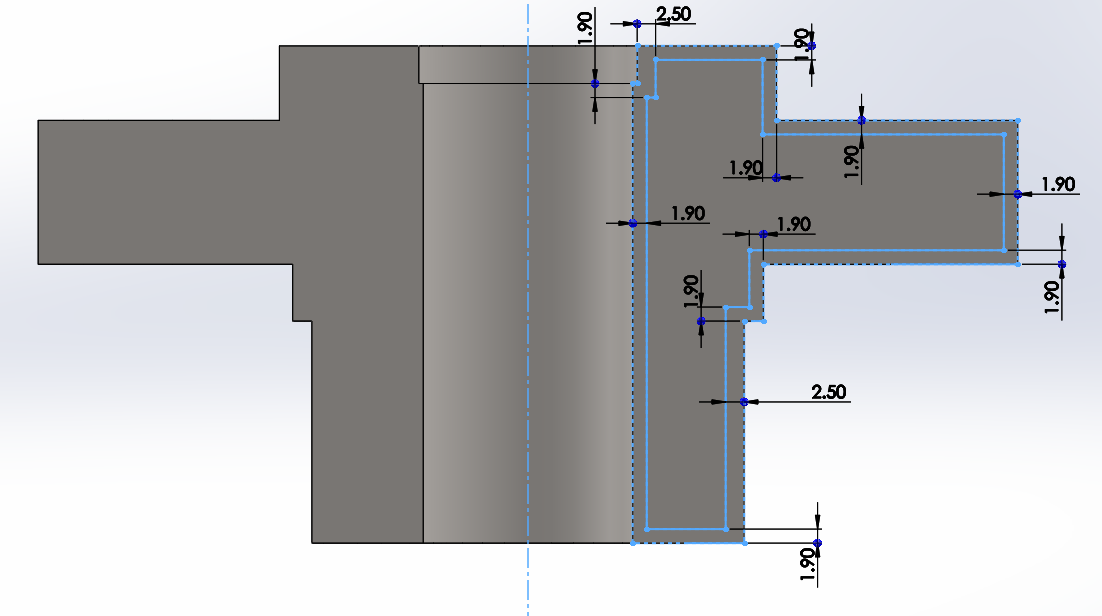


Fig. 2 Additives for part

**1.6 Determination of the drafts for die forging (external and internal)**

From the standard when we use mechanical presses the drafts for die forging will be:

* external - 5º
* internal - 7º

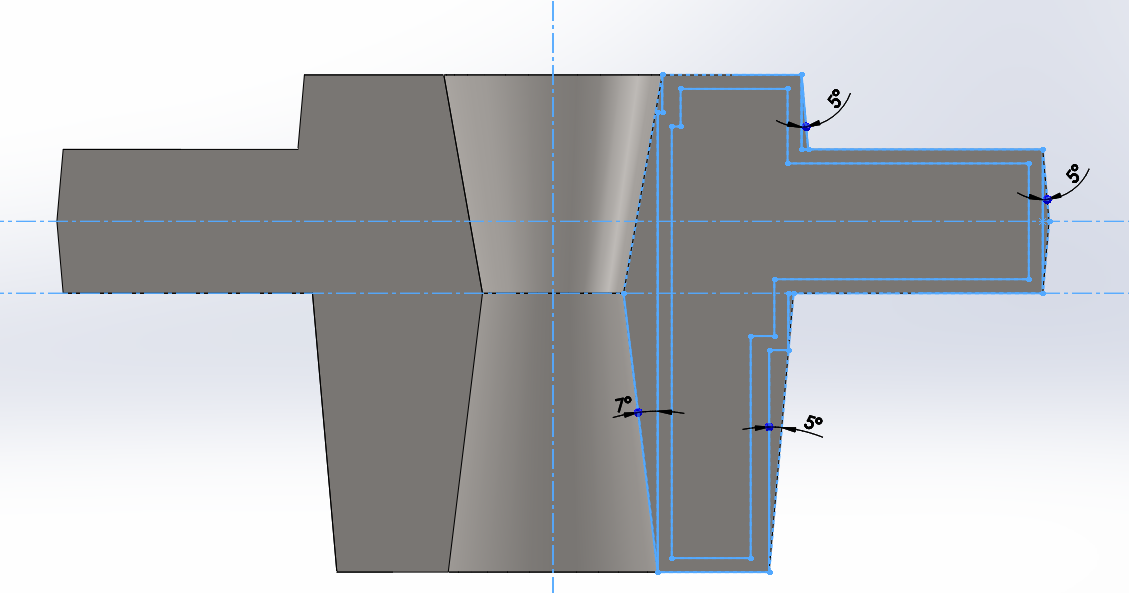


Fig. 3 Die drafts

**1.7 Determination of the fillet radii for die forging (external and internal);**

From the standard we use table 3 to determinate the external fillet (R). The internal fillet (r) will be. The external fillet is 2.5 mm and the internal is 5 mm. Therefore, we are making the additives bigger in order for the external fillet to not

Table 3. External fillet

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Mass of the Forged Part [Kg] | Depth of the tool cavity [mm] | | | |
| Up to 10 | From 10 up to 25 | From 25 up to 50 | Over 50 |
| External radii for the fillets [mm] | | | |
| Up to 1,0 | 1 | 1,5 | 2,0 | 3,0 |
| From 1,0 up to 6,0 | 1,5 | 2,0 | 2,5 | 3,5 |
| From 6,0 up to 16,0 | 2,0 | 2,5 | 3,0 | 4,0 |
| From 16 up to 40,0 | 2,5 | 3,0 | 4,0 | 5,0 |
| From 40,0 up to 100,0 | 3,0 | 4,0 | 5,0 | 7,0 |
| Over 100,0 | 4,0 | 5,0 | 6,0 | 8,0 |

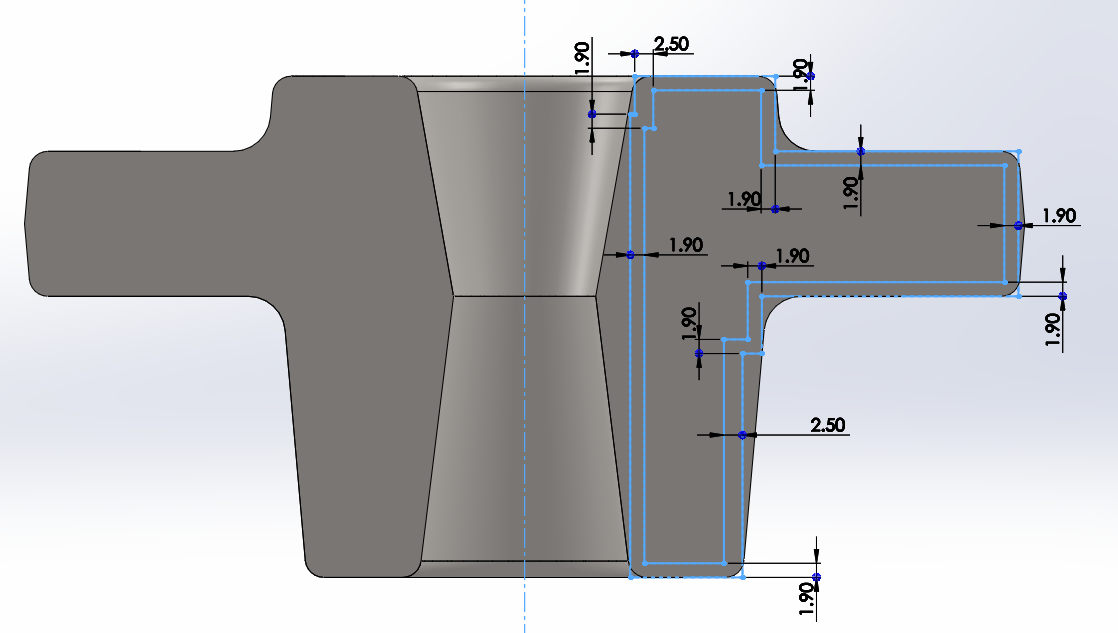


Fig. 4 Added External and Internal Fillets

**1.8 Determination of the position, shape and dimensions of the barrier metal layer for the openings in the forged part**

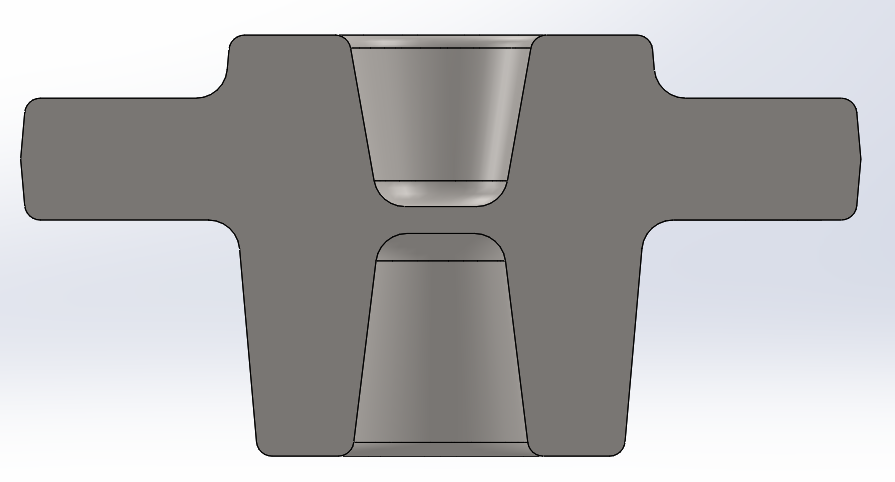


Fig 5. Position of the barrier layer

The shape and dimensions of the barrier metal layer is defined from the ratio of the height (hbl) and diameter (dbl) of the barrier metal layer in final step.

The ratio is between 0.4 < h/d < 0.85. Therefore, the width (S) of the barrier metal layer will be determined by the following formula:

**1.9 Determination of flash land and flash gutter configuration and flash mass**.

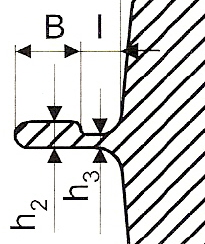
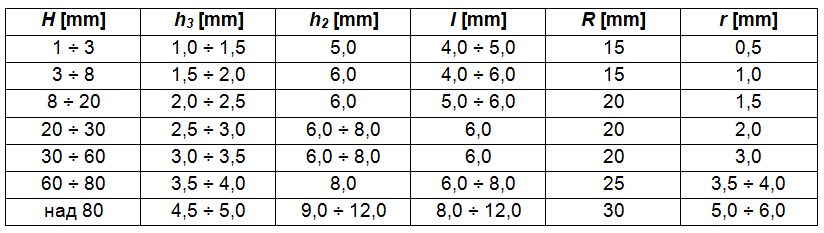


Fig. 6 Dimensions of the flash

Dimensions of gutter depend on flash thickness h3 on the flash ridge that may be calculated using the following expression:

For the dimension h3, choose the nearest higher tabular value of the calculated in the above formulas. We chose h3 = 2.50 mm because we will otherwise overload the mechanical press with a load of 12 MN instead of up to 10 MN. The main dimensions of technological flash ridge are given in table 4.

Table 4. Dimensions for the flash bridge



The dimension H is determined by the height of the forging and actually represents the depth of the cavity of the stamp (H1 / 3).

The value of B depends from the mass of the forging and is defined as follows:

- B = 20 mm when the mass of the forging is above 2 kg.

The other values are:

* h2 = 6 mm
* R = 20 mm
* r = 1.5 mm
* I = 5 mm

**1.10 Development of forged part drawing for die making**

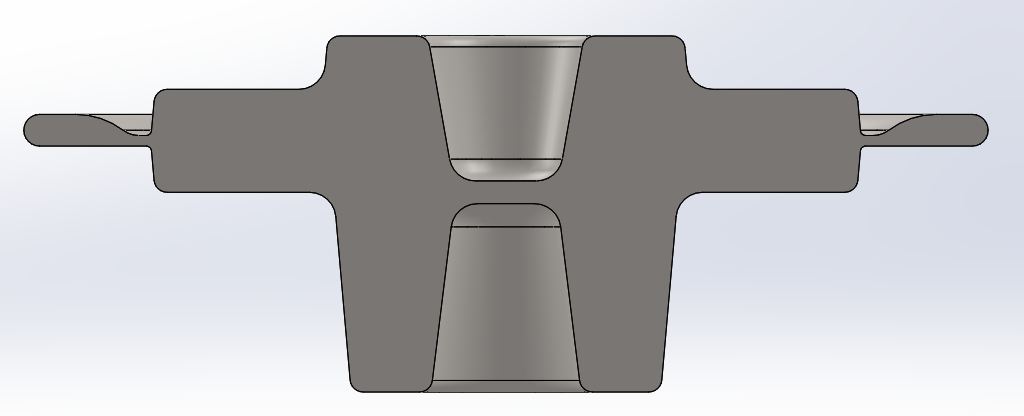
****

Fig. 7 Forged part half-section

The forged part drawing for making of finishing impression has been developed on a basis of inspection (acceptance) forged part drawing. The forged part drawing has been performed on the same scale with inspection drawing, and dimensions have placed with taking into account a shrinkage, i.e. increased by 1.5 % compared to design dimensions. The «hot forged part drawing» has been obtained.

**2.11 Determination of initial workpiece dimensions.**

The volume Vw of the workpiece is defined as the sum of the volume of the forging Vf (including the volumes of the barrier metal layers), the volume of the technological gutter Vg and volume from oxides Vo resulting from the combustion of the surface layer of the metal on heating.

Losses of metal from oxidation during heating of the workpiece is recorded by the coefficient δ [%] and depends from the mode of heating as follows:

1. If heated in a flame furnace with fuel oil -

2. for induction heating -

The volume of the workpiece is obtained directly in the Mass Properties of the 3D product (without taking the losses in value). The resulting value is increased (with the command Scale) to the value of δ.

To prevent buckling of forging and ease of cutting its ratio of size is selected in the range of 1.5 to 2.8.

For the particular problem we chose and the volume of the workpiece is

The calculated diameter of the workpiece is calculated by the formula:

The length of the forging is calculated by the formula:

**1.12 Determining the type and number of operation for hot forging**

We chose to use two operations (passes). The first being an axial upsetting (flat die forging) and the second being the final impression die forging. The following are pictures of the of the tools half-sections, respectively for the first and second operations.

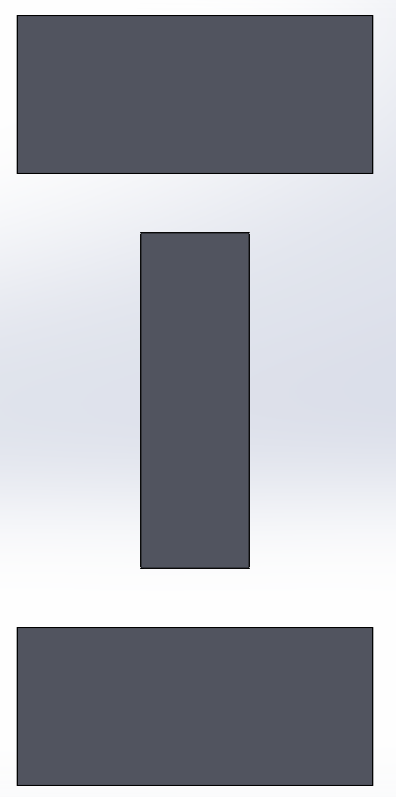


Fig. 8 Half-section of the tools for axial upsetting

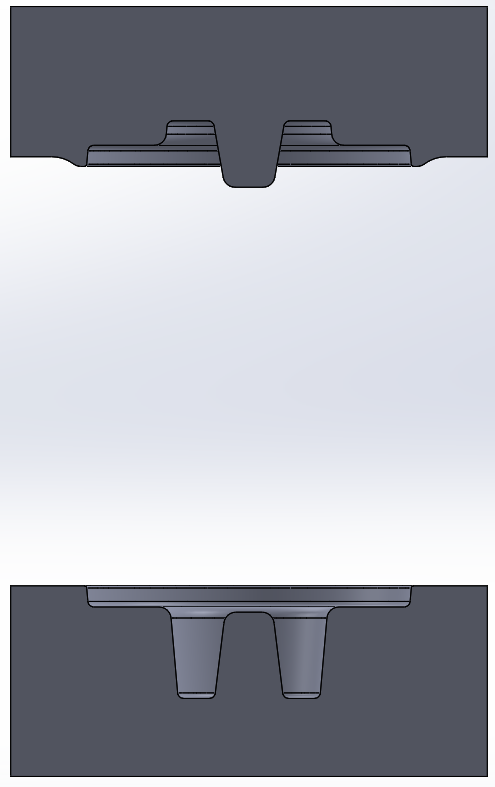


Fig. 9 Half-section of the tools for impression die forging.

**1.13. Determining the needed force for forging.**

The maximum value of the force in the end of the hot forging process for forged parts with circular shaped section in the parting plane are calculated by the following formula:

Where Re is the yield stress for the forged part material, I is the length of the gutter saddle, h is thickness of the gutter saddle, FM is the area of the gutter saddle, FF.P. is the area of the section of the forged part in the parting plane.

The yield stress value is determined from table 5.

Table 5. Yield stresses for different steels

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Temperature [oC] | Yield Stress for different type of steels [MPa] | | | |
| C25 | C35 | C45 | C50 |
| 700 | 131 | 104 | 140 | 89 |
| 800 | 70 | 70 | 65 | 46 |
| 900 | 48 | 56 | 55 | 16 |
| 1000 | 41 | 31 | 35 | 11 |
| 1100 | 24 | 21 | 22 | 8 |
| 1200 | 14 | 15 | 12 | 8 |

The values for FM, FF.P. can be easily measured with the help of SolidWorks’ Measure Tool and I and h can be taken from the gutter dimensions determined in **p.1.9**

**After the preliminary calculation we have .**

**1.14. Determining the temperatures and time needed for heating of the forged part.**

The best thing in this case is to use a direct-fired furnace with a sloping hearth for heating of cylindrical workpieces. The maximum temperature for heating the workpiece is 1200 °C, the minimum temperature of completing the forging is 900 °C. We chose the 1200 °C for heating the workpiece because if the temperature is any colder the load for Tool 1 goes over 10 MN.

1. **Simulation in QForm VX.**

**2.1. Analysis of the die impression filling.**

The die impression is oriented on the way that largest cavity is on the bottom because there is a danger of defects appearing within the longer upper half of the part.

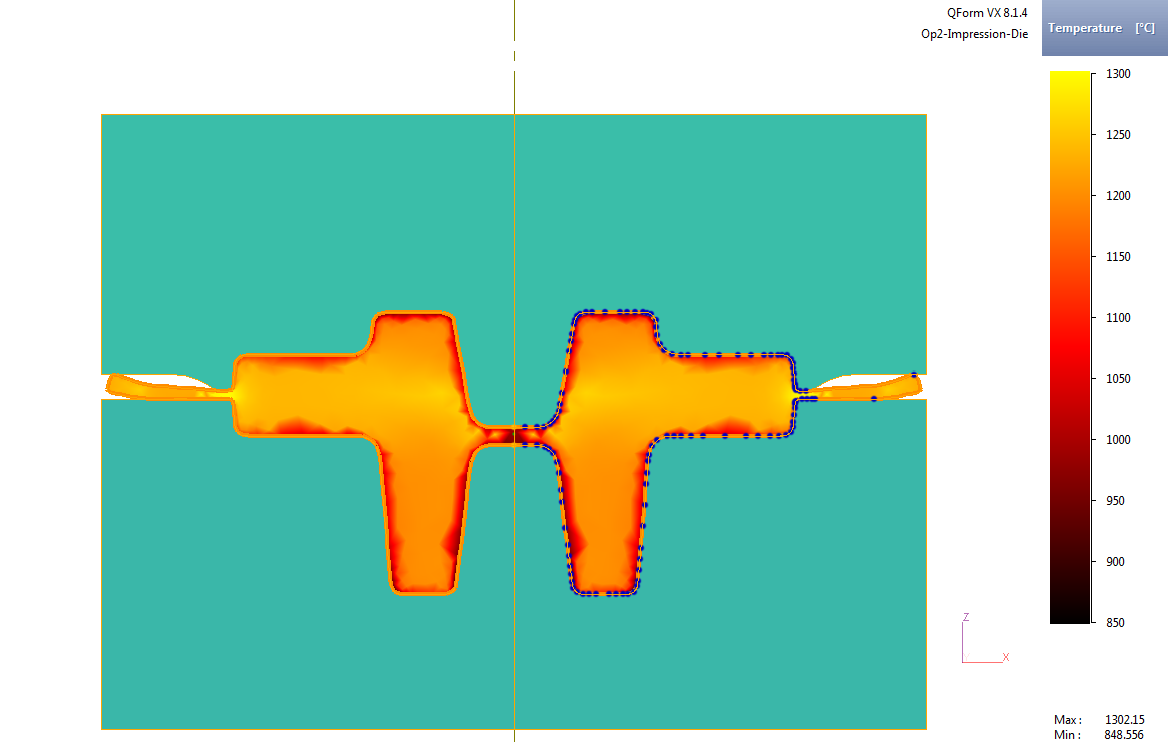


Fig. 10 Impression die filling. Distribution of the temperature and contact points.

The forged part is formed with no unfilled cavities, a little amount of metal has flown in the flash, as is seen from the figure above. **Therefore, the workpiece volume has been well calculated!**

* 1. **Analysis of force operation parameters of the equipment selected.**

The 10 MN press is selected.

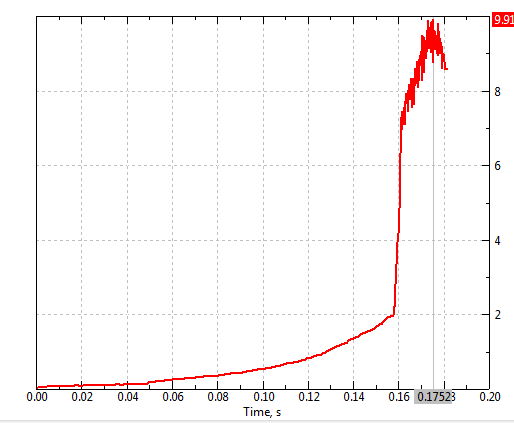
****

Fig. 11 Load graph for the impression die forging

It is shown clearly on the figures that deforming force is high. This is because of the high complexity of the initial detail (deep cavities).

**2.4. Analysis of temperature and deformation fields**

The hot forging temperature region for this material is 1200-700 oC.

There are dead zones formed in the bottom of the part during forging. The forged part is cooling faster there due to lack of deformation and the degree of deformation is not so high there. This is not true concerning the flash zone where the deformation zone is located during the whole process.

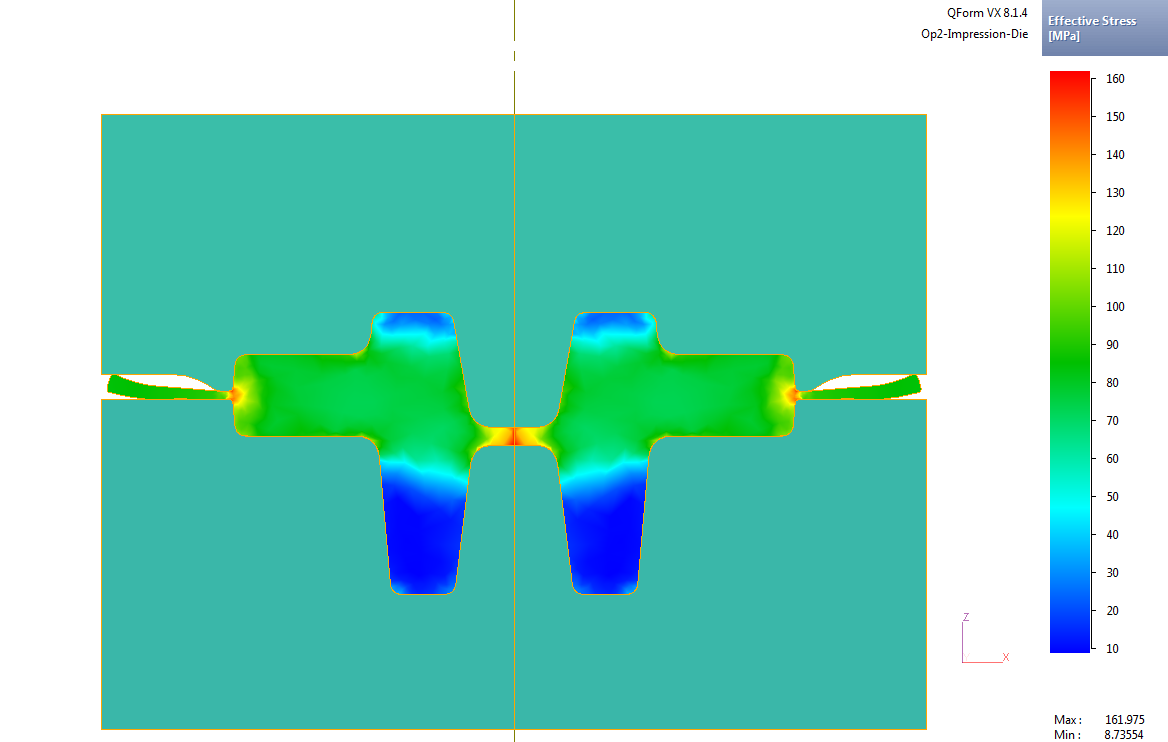


Fig. 12 Distribution of Effective stresses

1. **Conclusions**

A technological process has been developed for manufacturing of forgings for a coupling part in sequence of two operations (passes):

- First preliminary - axial upsetting (flat-die forging)

- Second and final - impression-die forging

Both operations use a mechanical press (10 MN).

The aim of the developed process was to have the least amount of material for mechanical processing. The low weight of the forged part of 3.3 kg and the successful forging without any imperfections/defects helped us to achieve our goal.

The disadvantages of the developed process lies in the height of the flash in the final stage of filling the die which is 2.5 mm. The flash height could have been lower as well as the heating temperature if the mechanical press was 16 MN instead of 10 MN.