UPSETTING COLD FORMING PROCESSES

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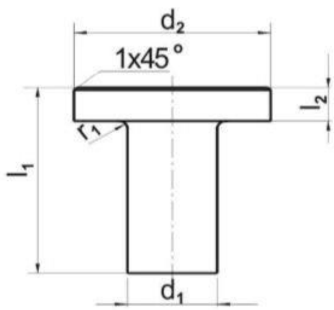
1. Introduction

A basic metal forming method called upsetting is applied in manufacturing, where a metal workpiece is squeezed to shorten its length and increase its cross-sectional area. This method is widely used in industries to form items like bolts, rivets, and fasteners. It is usually applied to materials that are cylindrical or bar-shaped. By changing the grain structure of the metal, upsetting improves its strength and mechanical qualities and frequently increases fatigue resistance. Depending on the material and application, it can be done in either hot or cold working conditions utilizing hydraulic presses or hammers.

2. Assigned Metal Project

2.1 Drawing and Dimensions Guidance



Data:

$d_1 = 6$	$l_1 = 19$	$r_1 = 1$
$d_2 = 12$	$l_2 = 6$	$r_2 = -$
$d_3 = -$	$l_3 = -$	$r_3 = -$
$d_4 = -$	$l_4 = -$	$r_4 = -$
$d_5 = -$	$l_5 = -$	$r_5 = -$

Assigned material: AI99.5 (Aluminium Alloy)

2.2 Given Tasks

- ❖ Plan the forming technology for the workpiece according to the figure and data below.
- ❖ Design the die of the last forming step.

2.3 Report Content

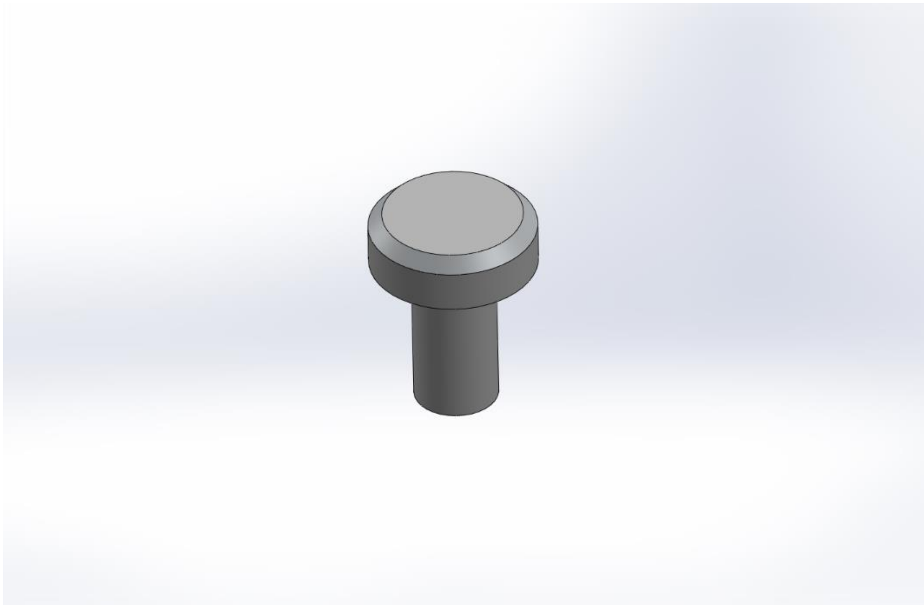
- ❖ Issued project sheet.
- ❖ Description of the forming steps; materials, geometries.
- ❖ Result of calculations: analytical and finite element (optional).
- ❖ Drawings: full die assembly drawing of the final forming step.
- ❖ Heat treatment of the active parts

Notes:

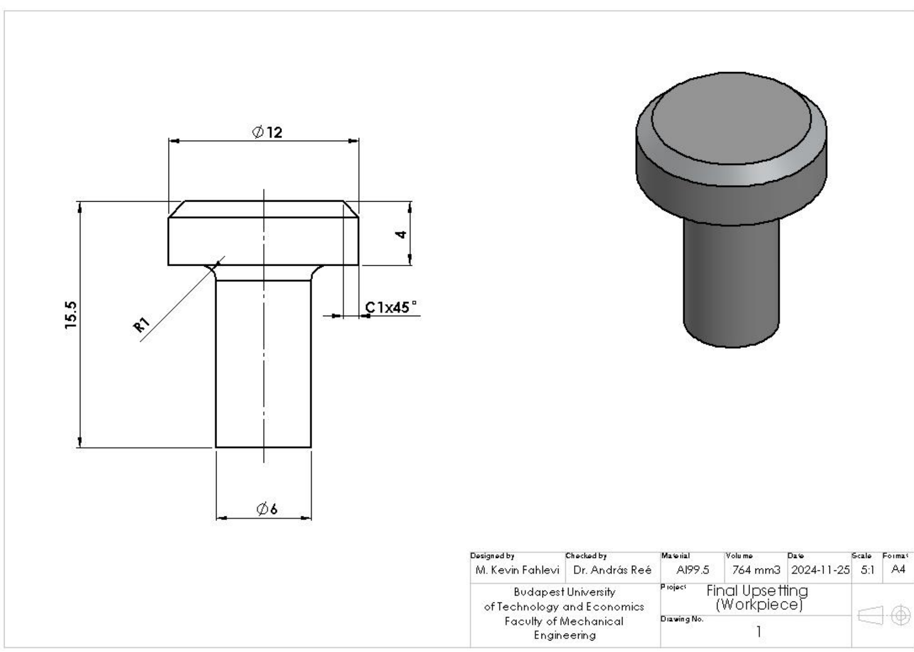
- ❖ Issued project: September 12, 2024.
- ❖ Submission deadline: December 7, 2024.

3 Workpiece in CAD

3.1 Isometric Model



3.2 2D Drawing



Note: The total height and the height of head/cap are slightly changed due to improper upsetting ratio resulted from the original dimensions.

4. Investigation of Workpiece Material

Grade :	ENAW-Al99.5
Number:	ENAW-1050A
Classification:	Aluminium - 1000 series/ Attention! Grade ENAW-1350 also named ENAW-Al99.5
Density	2.7 g/cm ³
Standard:	EN 573-3: 2009 Aluminium and aluminium alloys. Chemical composition and form of wrought products. Chemical composition and form of products EN 755-2: 2008 Aluminium and aluminium alloys. Extruded rod/bar, tube and profiles. Mechanical properties EN 485-2: 2008 Aluminium and aluminium alloys. Sheet, strip and plate. Mechanical properties EN 754-2: 2008 Aluminium and aluminium alloys. Cold drawn rod/bar and tube. Mechanical properties EN 546-2: 1997 Aluminium and aluminium alloys. Foil. Mechanical properties EN 683-2: 2006 Aluminium and aluminium alloys. Finstock. Mechanical properties EN 1301-2: 1997 Aluminium and aluminium alloys. Drawn wire. Mechanical properties EN 570: 2007 Aluminium and aluminium alloys. Impact extrusion slugs obtained from wrought products. Specification EN 851: 1996 Aluminium and aluminium alloys. Circle and circle stock for the production of culinary utensils. Specifications EN 941: 1996 Aluminium and aluminium alloys. Circle and circle stock for general applications. Specifications EN 1386: 2007 Aluminium and aluminium alloys. Tread plate. Specifications EN 1396: 2007 Aluminium and aluminium alloys. Coil coated sheet and strip for general applications. Specifications EN 12392: 2000 Aluminium and aluminium alloys. Wrought products. Special requirements for products intended for the production of pressure equipment EN 1715-3: 2008 Aluminium and aluminium alloys. Drawing stock. Specific requirements for mechanical uses (excluding welding) EN 1715-4: 2008 Aluminium and aluminium alloys. Drawing stock. Specific requirements for welding applications

Chemical composition % of grade ENAW-Al99.5 (ENAW-1050A)

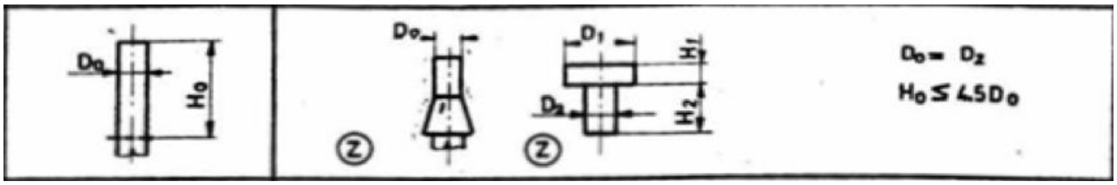
Fe	Si	Mn	Ti	Al	Cu	Mg	Zn	Others
max 0.4	max 0.25	max 0.05	max 0.05	min 99.5	max 0.05	max 0.05	max 0.07	each 0.03;

Mechanical properties of grade ENAW-Al99.5 (ENAW-1050A)

Rm - Tensile strength (MPa) (F) (H112)	**60**
Rm - Tensile strength (MPa) (0) (H111)	**60-95**
$\mathbf{R_{p0.2}}$ 0.2% proof strength (MPa) (F) (H112)	**20**
$\mathbf{R_{p0.2}}$ 0.2% proof strength (MPa) (0) (H111)	**20**
A - Min. elongation at fracture (%) (F) (H112)	**25**
A - Min. elongation Lo = 50mm (%) (F) (H112)	**23**
Brinell hardness (HBW): (F) (H112)	**20**
Brinell hardness (HBW): (O)	**23**

5. Technology Operation

The use of assistance sheet provided within the course is essential to determine the proper forming operation which is suitable for the part, considering various parameters of the part. In this project, the upsetting technique is chosen for the technology operation.



Due to the cross-section of the workpiece, the upsetting process required two steps: pre-upsetting and final upsetting. The design process includes making the right die set to reach the final shape of the workpiece with proper physical characteristics. Additionally, the determination of the forces and its procedure should be taken into account, by tracking how the workpiece changes from the original shape.

6. Technology Calculation

Based on the list of aluminium-alloy materials shown in CAD software (SolidWorks), **1060 Alloy** would be the most appropriate to the Al99.5 material. The **1060 Alloy** consists of about 99.6% aluminum, making it a close match to the Al99.5 designation, which typically refers to aluminum with a purity of 99.5%.

6.1 Properties of Workpiece Model

The calculation of product volume of the part model can be found in CAD together with other mechanical properties, after assigning the material into the model. List of the properties are written below:

a. Mass = 2.06 grams
b. Volume = 764 cubic millimeters mm^3
c. Surface area = 562.73 square millimeters
d. Center of mass: (millimeters)
   X = 0.00
   Y = 3.78
   Z = 0.00
e. Principal axes of inertia and principal moments of inertia: (grams*square millimeters)
   Taken at the center of mass.
   Ix = (0.00, 1.00, 0.00) Px = 324.51

Iy = (0.00, 0.00, 1.00) Py = 53.07
Iz = (1.00, 0.00, 0.00) Pz = 53.07

f. Moments of inertia: (grams*square millimeters) Taken at the center of mass and aligned with the output coordinate system. (Using positive tensor notation.)

Lxx = 53.07	Lxy = 0.00	Lxz = 0.00
Lyx = 0.00	Lyy = 24.51	Lyz = 0.00
Lzx = 0.00	Lzy = 0.00	Lzz = 53.07

g. Moments of inertia: (grams*square millimeters) Taken at the output coordinate system. (Using positive tensor notation.)

Ixx = 82.51	Ixy = 0.00	Ixz = 0.00
Iyx = 0.00	Iyy = 24.51	Iyz = 0.00
Izx = 0.00	Izy = 0.00	Izz = 82.51

Intrinsic and Extrinsic properties also can be obtained from the selected material for the workpiece. Those properties can be seen below:

a. Elastic Modulus = 69000 N/mm^2
b. Poisson's Ratio = 0.33
c. Shear Modulus = 27000 N/mm^2
d. Mass Density = 2700 kg/m^3
e. Tensile Strength = 68.9356 N/mm^2
f. Yield Strength = 27.5742 N/mm^2
g. Thermal Expansion Coefficient =2.4e-05 /K
h. Thermal Conductivity = 200 W/(m·K)
i. Specific Heat = 900 J/(kg·K)

6.2 Stock Original Height

To start the calculation for the initial height of the given stock, the initial cross section area of the stock can be calculated first. The formula is as follows:

$$d0 = d1 = 6\ mm, \qquad A0 = \frac{\pi * d0^2}{4} = \frac{\pi * 6^2}{4} = 28.27 \sim 28.3\ mm^2$$

The volume can be assumed constant before and after the operations since there is no chips produced during the forming process.

$$V0 = V1, \qquad h0 = \frac{V1}{A0} = \frac{764}{28.3} = 26.99 \sim 27\ mm$$

Where d_0: Initial diameter
A_0: Initial cross-section area
h_0: Initial height
V_0: Volume before forming operation
V_1: Volume after forming operation

The resulted initial height value is exactly equal the requirement parameter in the chosen technology operation, which $h0 \leq 4.5d0$. A value 27 [mm] for the initial height is perfect.

6.3 Upsetting Ratio

Since upsetting operation will be used for producing this metal with given dimension parameters, so the upsetting ratio is an important property to be calculated to determine the number of stages need to be done. The ratio can be found by initial height over the initial diameter.

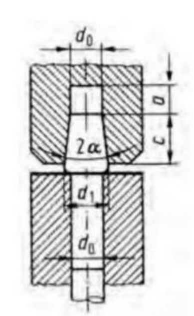
$$s = \frac{h0}{d0} = \frac{27}{6} = 4.5$$

The upsetting ratio in metal forming (initial height/initial diameter) helps assess the deformation conditions. A value of 4.5 is the upper limit for 2-cycles upsetting operations. Therefore, pre-upsetting and the final upsetting process can indeed be a practical solution. Performing the pre-upsetting in can reduce the height-to-diameter ratio gradually, which can help prevent instability, buckling, and excessive frictional forces that could arise from a single, large deformation.

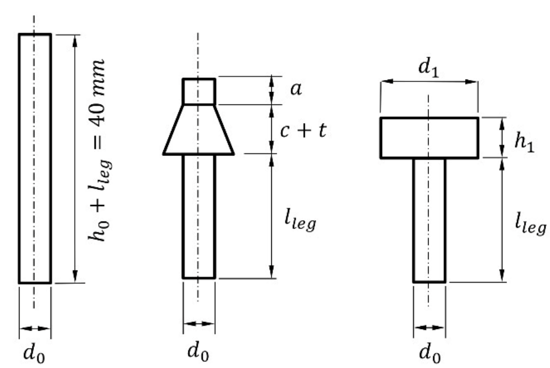
6.4 Preforming

As this metal forming operations need to have two-times upsetting processes, therefore there will be two different shape changes on the metal on each preforming operation. In general, the original shape of stock will change into a cone in between the cylindrical sections, and cylindrical head as a last forming stage will be formed. Cone angle, guide length, and length of the tapered part of the pre-former must be taken into account. The reference is displayed in the following table:

Forming in two steps – pre-form shape



Upsetting ratio	Cone angle	Guide length	Length of the tapered part of the pre-former
$s = h_0/d_0$	2α [degree]	a [mm]	c [mm]
2.5	15	$0.6\,d_0$	$1.37\,d_0$
3.3	15	$1.0\,d_0$	$1.56\,d_0$
3.9	15	$1.4\,d_0$	$1.66\,d_0$
4.3	20	$1.7\,d_0$	$1.66\,d_0$
4.5	25	$1.9\,d_0$	$1.45\,d_0$



Since 4.5 upsetting ratio is included in the table displayed, then the given parameters can be used to find the cone angle (α), guide length (a) and length of the tapered part (c).

Cone angle:

$$2\alpha = 25°$$

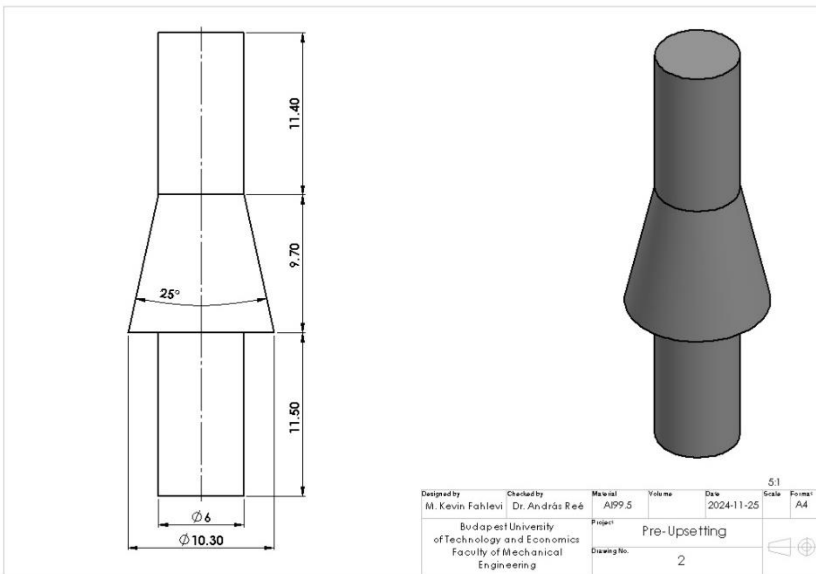
Guide length:

$$a = 1.9 * d0 = 1.9 * 6 = 11.4\,mm$$

Tapered length:

$$c = 1.45 * d0 = 1.45 * 6 = 8.7\,mm, \quad c + t = 8.7 + 1 = 9.7\,mm, \quad where\ t = 1\,mm$$

Schematic Drawing:



6.5 Formability-Principle Strain

Formability refers to a material's capacity to deform plastically without fracturing. In upsetting, where a workpiece is compressed to reduce height and increase diameter, formability is critical to achieving the desired shape while avoiding defects like cracking or buckling. The formula to calculate the formability is as follows:

h1= l2= 4 mm, $\varphi 1 = \ln\left(\frac{h0}{h1}\right) = \ln\left(\frac{27}{4}\right) = 1.9$

A compressive strain of around 1.9 is relatively high for formability in upsetting, so whether it's a "good" range depends on the material's ductility and the specific forming conditions. Thanks to the assigned material – Aluminium Alloy – which has ductile material properties, it is able to generally handle high strains without cracking, making 1.9 a feasible strain in this case.

6.6 Flow Stress

In upsetting, flow stress is a critical factor, as it represents the stress required to continue deforming the material plastically. Generally, there are two constant parameters will be used in the equation of flow stress. The constant values can be seen in the table below.

Material	C_1 [MPa]	C_2 [MPa]	C_3 [MPa]	C_4	n	Material	C_1 [MPa]	C_2 [MPa]	C_3 [MPa]	C_4	n	Material	C_1 [MPa]	C_2 [MPa]	C_3 [MPa]	C_4	n
Al 99.5		148			0.20	C10	258	421			0.658	BC 1		855.8			0.2269
Al 99.5		145.6			0.1995	C10 K		697			0.225	BC 1		872			0.227
Al 99.5 fk 08		140.5			0.0442	C10K		683.5			0.2249	BC 2		915.9			0.2042
Al 99.7 0.1/s		132.8			0.2788	HF10		758.8			0.2051	Cr 1		909			0.181
Al 99.7 2.5/s		139.6			0.2733	ZC 10		701			0.233	Cr 2		951.1			0.2111
AlMgSi	25.5	152.5			0.405	LH2		700			0.2721	CrV 1		991.8			0.1737
AlMgSi		182			0.2865	C15 K		738			0.265	CrV 1		1012			0.174
AlMgSi1	68	153.5			0.246	C15K		724			0.265	CrV 3		1053			0.1644
AlMgSi1		227			0.143	C20	280.3	418.3			0.309	CMo 3		903.8			0.1928
AlMgSi1		223			0.1428	C25K		764.8			0.2352	CMo 4		1032			0.1349
AlMg1Si1		229.9			0.1663	C35 K		902			0.241	MnS 2		1149			0.1754
AlCuMg1		334.5			0.2124	C35K		884.9			0.2408	X10CrNiTi18.9 20°C	787	402	-550.4	-5.06	1
AlCuMg2		336.2			0.1547	C45 K		958			0.196	X10CrNiTi18.9 200°C		861			0.3308
AlMg3		414			0.2245	C45K		939.6			0.1964	GO 3		1101			0.1349
AlZnMgTi		336			0.1334	C55		959			0,128	GO 3		1123			0.21
CuE	84	286.4			0.442	K1H 12	504	177.1	-194.7	-9.4	1	KO 13		1452			0.148
CuE		364.7			0.27	K2H 08	470,3	200,4	-205,8	-7,94	1	Fermax	113.5	453.1			0.298
CuE		371			0.27	M2H 08	449.7	163.7	-211.7	-8.4	1						
CuZn37	125	554.9			0.332	M2H 09		568.7			0,162						
CuZn37		656			0.290	M2H 12	485,4	185,2	-247,7	-9,9	1						
CuZn37		643.6			0.2896	M2H 15	530,7	75,7	-267,5	-4,1	1						
CuZn37 fk		1051,4			0,1057	M2H 20	456,5	108,3	-208,4	-7,4	1						
CuZn30	110	510			0.309												
CuZn28		614.8			0.3351												
CuZn28		627			0.335												

According to the table, for the assigned material Al 99.5, the value of C_2 is 148 MPa, meanwhile the value of C_1 can be assumed zero. For the n-value, 0.20 is a good value to be applied in the formula. The calculation of the flow stress can be derived in a such way:

$$\sigma f = C1 + C2\ \varphi^n = C2\ \varphi^n = 148 * 1.9^{0.20} = 168.27 \sim 168.3\ MPa$$

6.7 Force at Pre-Forming

The force during preforming in the pre-upsetting process of metal forming plays a crucial role in shaping the workpiece before final forging. Pre-upsetting is typically performed to redistribute material, reduce height, increase diameter, or adjust the cross-sectional area to achieve a more favorable geometry for subsequent forming stages.

$$F01 = A01 * \ \sigma 01 = \frac{\pi * d01^2}{4} * \sigma f01, \qquad \varphi 01 = 2\ln\left(\frac{d01}{d0}\right) = 2\ln\left(\frac{10.30}{6}\right) = 1.08$$

$$\sigma f01 = C2\ \varphi 01^n = 148 * 1.08^{0.20} = 150.29 \sim 150.3\ MPa$$

$$F01 = \frac{\pi * d01^2}{4} * \sigma f01 = \frac{\pi * 10.30^2}{4} * 150.3 = 12{,}523.43\ N = 12.52\ kN$$

6.8 Work at Pre-Forming

The work done during the pre-forming stage is the product of the deformation force and the displacement over which the force acts. Mathematically, it is expressed as:

$$W = \int F\,dx$$

Where F: Deformation force as a function of displacement (x).
x: Displacement of the material during the deformation.

In this pre-upsetting process, the work done is calculated as follows:

$$W01 = F01 * \Delta h0, \qquad Where\ \Delta h0 = h0 - a - c - t = 27 - 11.4 - 8.7 - 1$$

$$= 5.9\ mm = 0.0059\ m$$

$$W01 = 12{,}523.43 * 0.0059 = 73.88\ J$$

6.9 Force at Ready-Forming

The force at ready forming in the upsetting process of metal forming refers to the total force required to initiate and sustain the deformation of a workpiece under compression between two dies. In this process, the height of the workpiece decreases while its diameter increases, with the material undergoing plastic deformation.

$$F1 = A1 * \sigma f1 * \left(1 + \frac{1}{3} * \mu * \frac{d2}{l2}\right), \qquad A1 = \frac{\pi * d2^2}{4} = \frac{\pi * 12^2}{4} = 113\ mm^2$$

$$\sigma f1 = C2\ \varphi 1^n = 148 * 1.9^{0.20} = 168.27 \sim 168.3\ MPa, \qquad \mu = 0.1$$

$$F1 = A1 * \sigma f1 * \left(1 + \frac{1}{3} * \mu * \frac{d2}{l2}\right) = 113 * 168.3 * \left(1 + \frac{1}{3} * 0.1 * \frac{12}{4}\right)$$

$$= 20{,}919.69\ N = 20.92\ kN$$

6.10 Work at Ready-Forming

In the context of upsetting, the work done at ready forming refers to the energy required to plastically deform the workpiece during the initial stages of the upsetting process. This involves compressing the material between two dies, where the height decreases, and the cross-sectional area increases.

The total work done during the ready forming stage is the integral of the deformation force over the distance of deformation. For upsetting, this can be expressed as:

$$W = \int_{h_i}^{h_f} F\,dh$$

Where F: The instantaneous force required for deformation at a given height.

h_i: Initial height of the workpiece.

h_f: Final height of the workpiece after ready forming.

The calculation of work done at ready forming is calculated upon the force at ready forming, as follows:

$$W1 = \frac{V1 * \sigma avg * \varphi avg}{\eta}, \qquad Where\ \sigma avg = \frac{\sigma f01 + \sigma f1}{2} = \frac{150.3 + 168.3}{2} = 159.3\ MPa$$

$$\varphi avg = \frac{\varphi 01 + \varphi 1}{2} = \frac{1.08 + 1.9}{2} = 1.49 \sim 1.5, \qquad \eta = 0.6$$

$$W1 = \frac{0.764 * 159.3 * 1.5}{0.6} = 304.26\,J$$

6.11 Parallel Forming

Assume, as it usual, the two forming stages are used the same tooling and forming machine which makes possible to make the two steps parallel. Therefore, the total force at one machine stroke is the sum of the two forces:

$$Fstroke = F01 + F1 = 12.52 + 20.92 = 33.44 \sim 33.5\ kN$$

The total work at one stroke is the sum of the two works:

$$Wstroke = W01 + W1 = 73.88 + 304.26 = 378.14\,J$$

Assume, the forming machine can make 80 strokes per minute (that means 80 workpieces), therefore the work for one second:

$$W = \frac{80}{60} * Wstroke = 1.33 * 378.14 = 502.92\,J$$

The minimum required power and minimum load ability of the forming machine to perform the given technology:

$$Pmin = 0.5029\ kW, \quad Fmin = 33.5\ kN$$

In addition, the tooling has to be applicable on the forming machine to perform the given technology.

7. Die Dimensioning and Construction

The die design and construction for the upsetting process in metal forming involve creating durable, precise tools to deform metal workpieces by compressing them along their axis, increasing diameter while reducing height. Dies, typically made of hardened tool steel or carbide, must withstand high compressive forces, resist wear, and provide a smooth surface to minimize friction and prevent defects. The die set includes an upper die (punch) to apply force, a lower die (base die) to support the workpiece, and guiding mechanisms to ensure alignment. The cavity geometry is designed to match the desired product shape, incorporating draft angles for easy removal, fillets to prevent stress concentrations, and venting systems to allow trapped air to escape.

Die construction involves CNC machining or EDM to shape the cavity, heat treatment for strength, and surface coatings to reduce wear and enhance performance. During the process, the workpiece is positioned in the die cavity, where controlled metal flow ensures the desired shape is achieved under compressive forces. Proper design is crucial to manage high stress and heat, ensure product quality, and maintain tool longevity. The die required for the final upsetting stage has the following active element, where the forming pressure experienced by the active part is:

$$Forming\ pressure: Pform = 0.8 * \sigma avg = 0.8 * 159.3 = 127.44\ MPa$$

7.1 Stresses at Active Elements

7.1.1 Punch

This part does the actual pressing of the part into the desired shape. Stress on the punch during the upsetting process is calculated as follows:

$$\sigma punch = \frac{Fstroke}{Apunch} = \frac{33500}{113} = 296.46\ MPa$$

$$Where\ the\ area\ of\ the\ punch: Apunch = A1 = \frac{\pi * d2^2}{4} = \frac{\pi * 12^2}{4} = 113\ mm^2$$

7.1.2 Ejector

This part hold prevents axial movement of the part during the upsetting process and pushes it out afterwards. The stress on the ejector during the upsetting process is:

$$\sigma ejector = \frac{Fstroke}{Aejector} = \frac{33500}{28.27} = 1185\ MPa, \quad d0 = d1$$

$$Where\ the\ area\ of\ the\ ejector: Aejector = \frac{\pi * d1^2}{4} = \frac{\pi * 6^2}{4} = 28.27\ mm^2$$

7.1.3 Die

The design of the bottom die is crucial for controlling the metal flow during the upsetting process, as it helps to shape the base of the upset part and maintain the required dimensions. Additionally, the bottom die must be made of high-strength, wear-resistant materials to endure the repeated impact and compressive loads. It may include features like fillets to reduce stress concentrations, venting systems to allow trapped air or gas to escape, and provisions for lubrication to minimize friction and heat generation.

7.2 Material Selection

For Al99.5 aluminum alloy and cold forming process, a material such as 60WCrV7 tool steel is a versatile and effective choice for all three active components – punch, ejector, bottom die - due to its excellent wear resistance and toughness, which are essential for handling the high compressive stresses during the deformation of metal.

60WCrV7 cold-work tool steel contains Chrome, Manganese, Phosphorus, Silicon, Sulfur, Tungsten and Vanadium. Chromium enhances hardenability, wear resistance, and corrosion resistance, while tungsten and vanadium form hard carbides, boosting wear resistance, toughness, and grain refinement. Manganese improves toughness and hardenability, and silicon adds strength and acts as a deoxidizer. Sulfur and phosphorus improve machinability but must be controlled to avoid brittleness. Together, these elements make the steel highly durable, wear-resistant, and suitable for cold-work applications requiring toughness and strength.

7.2.1 Chemical Composition of 60WCrV7 Steel

The following data sheets summarize 60WCrV7 steel properties such as chemical composition, physical and mechanical properties, etc.

60WCrV7 Chemical composition(mass fraction)(wt.%)									
Chemical			Min.(%)				Max.(%)		
C	Si	Mn	P	S	Cr	Ni	Mo	V	Ta
0.55-0.65	0.50-0.70	0.15-0.45	Max 0.030	Max 0.030	0.90-1.20			0.10-0.20	
W	N	Cu	Co	Pb	B	Nb	Al	Ti	Other
1.80-2.10									

7.2.2 Physical Properties of 60WCrV7 Steel

60WCrV7 cold-working alloy tool steel exhibits high hardness, excellent wear resistance, and good toughness, making it durable under high-pressure conditions. Its fine grain structure, enhanced by vanadium, ensures consistent strength and improved fatigue resistance. The steel maintains dimensional stability during heat treatment and machining due to its balanced composition. While it offers limited heat resistance, it is highly suited for applications requiring high compressive strength and abrasion resistance in cold-working environments.

60WCrV7 Physical Properties		
Tensile strength	115-234	σb/MPa
Yield Strength	23	σ 0.2 ≥/MPa
Elongation	65	δ5≥ (%)
ψ	-	ψ≥ (%)
Akv	-	Akv≥/J
HBS	123-321	-
HRC	30	-

7.2.3 Mechanical Properties of 60WCrV7 Steel

60WCrV7 cold-work tool steel offers excellent mechanical properties, including high hardness and compressive strength, making it ideal for withstanding heavy loads and abrasion. Its wear resistance is enhanced by hard carbide formations from chromium, tungsten, and vanadium, ensuring durability in demanding applications. The steel also exhibits good toughness, allowing it to resist cracking under impact or repeated stress. Additionally, it provides excellent dimensional stability after heat treatment, ensuring precise and consistent performance in cold-working operations.

60WCrV7 Mechanical Properties		
Tensile strength	231-231	σb/MPa
Yield Strength	154	σ 0.2 ≥/MPa
Elongation	56	δ5≥(%)
ψ	-	ψ≥(%)
Akv	-	Akv≥/J
HBS	235-268	-
HRC	30	-

7.3 Heat Treatment

The heat treatment process for 60WCrV7 tool steel is designed to enhance its mechanical properties, such as hardness, toughness, and wear resistance, while ensuring dimensional stability and stress relief. By carefully controlling the heating, cooling, and tempering stages, the material's performance can be optimized for demanding cold-work applications.

7.3.1 Heat Treatment Stages

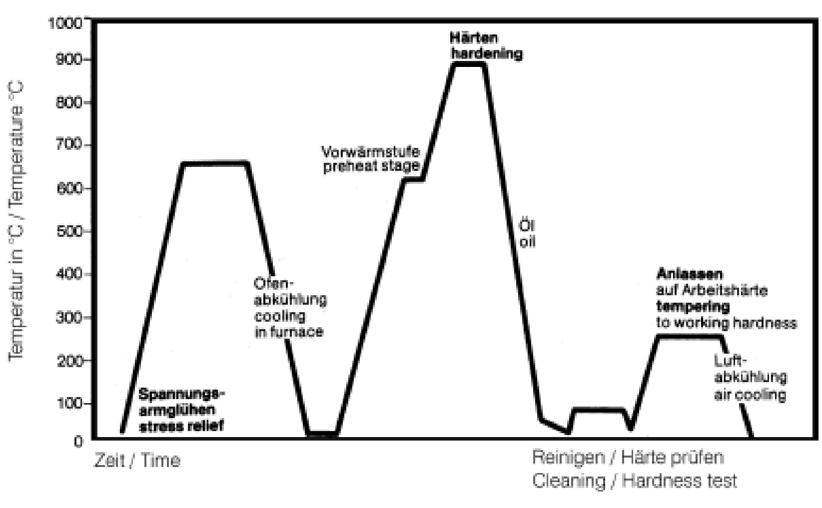
The following heat treatment processes stages are recommended for H13 Tool Steel.

- Annealing
  - Temperature: 710 - 7450 ºC or 1310 – 1382 ºF.
  - Cooling: Slow controlled cooling in furnace at a rate of 10 to 20 °C/hr (18 to 36 °F/hr) down to approximately 600 °C (1112 °F), further cooling in air.

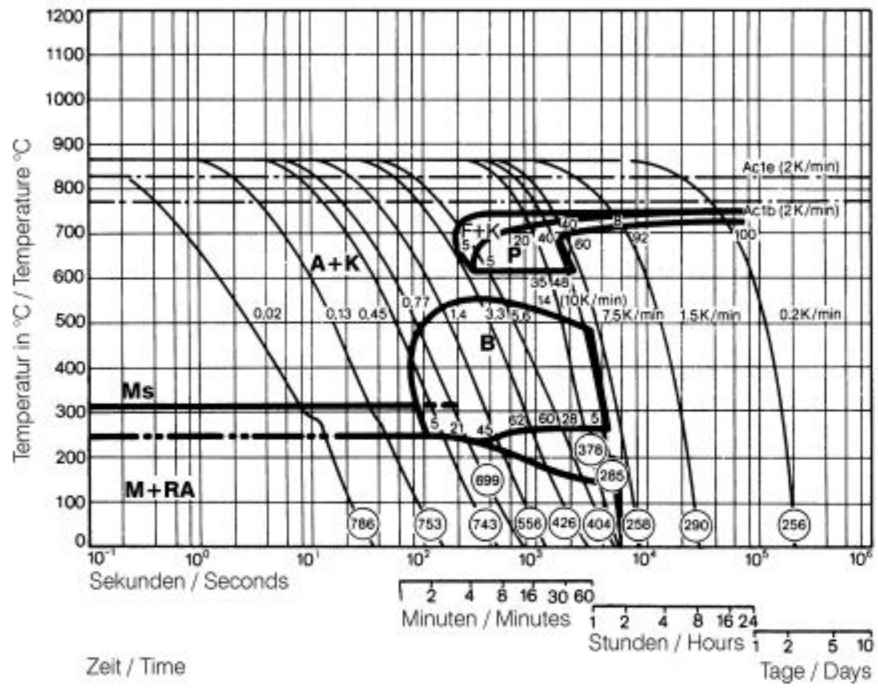
- Stress-Relieving
  - Temperature: 650 or 1202 ºF.
  - Cooling: After through heating, hold in neutral atmosphere for 1-2 hours. Slow cooling in furnace, intended to relieve stresses caused by extensive machining or in complex shapes.

- Hardening and Tempering
  - Temperature: 870 - 900 ºC or 1598 – 1652 ºF.
  - Cooling: Quenching in Oil, holding time after temperature equalization: 15 to 30 minutes. After hardening, tempering to the desired working hardness according to the tempering chart.

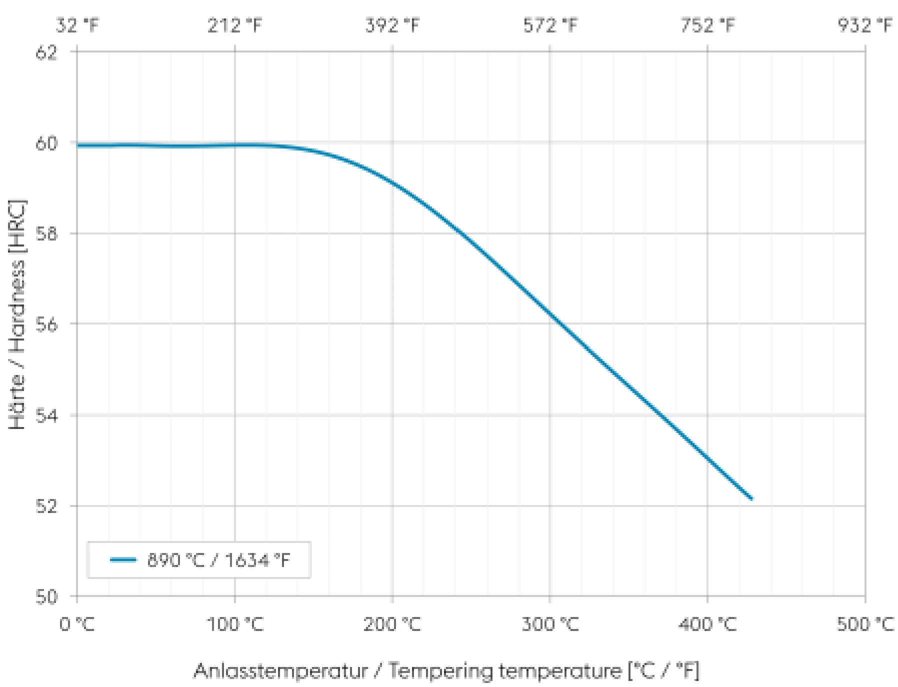
7.3.2 Thermal Cycle Diagram



7.3.4 Continuous Cooling Transformation Diagram

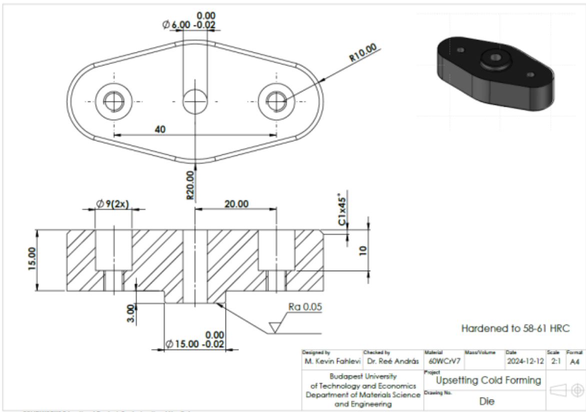


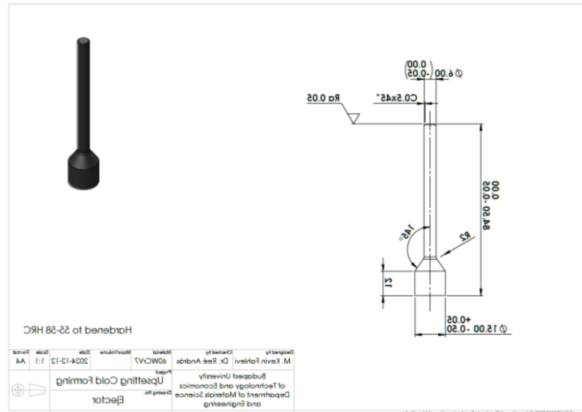
7.3.5 Tempering Diagram

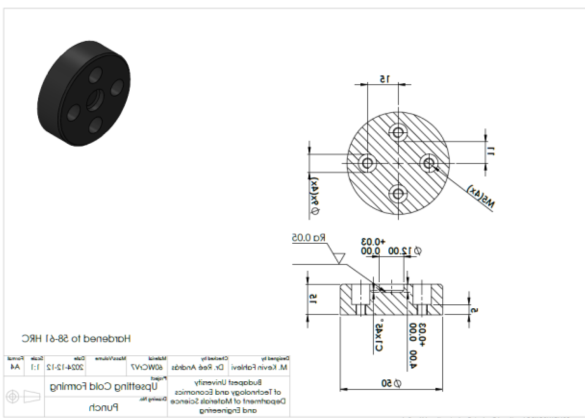


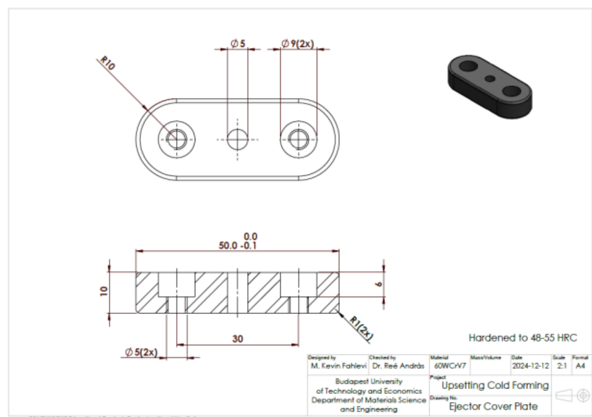
8. CAD Models and Drawings

8.1 Active Elements CAD Drawings

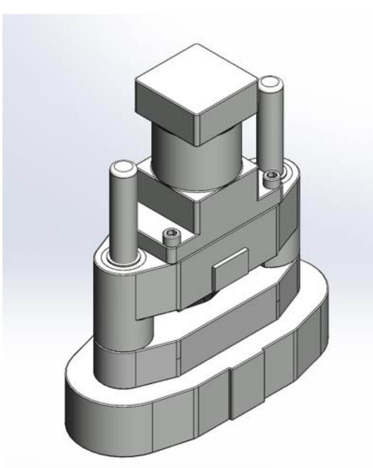




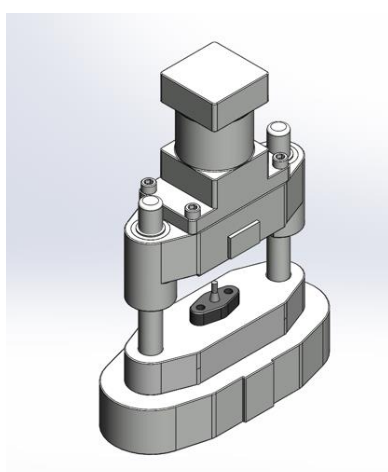




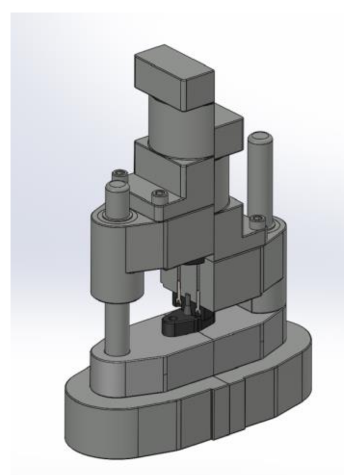
8.2 Assembly CAD Models



Full-closed arrangement

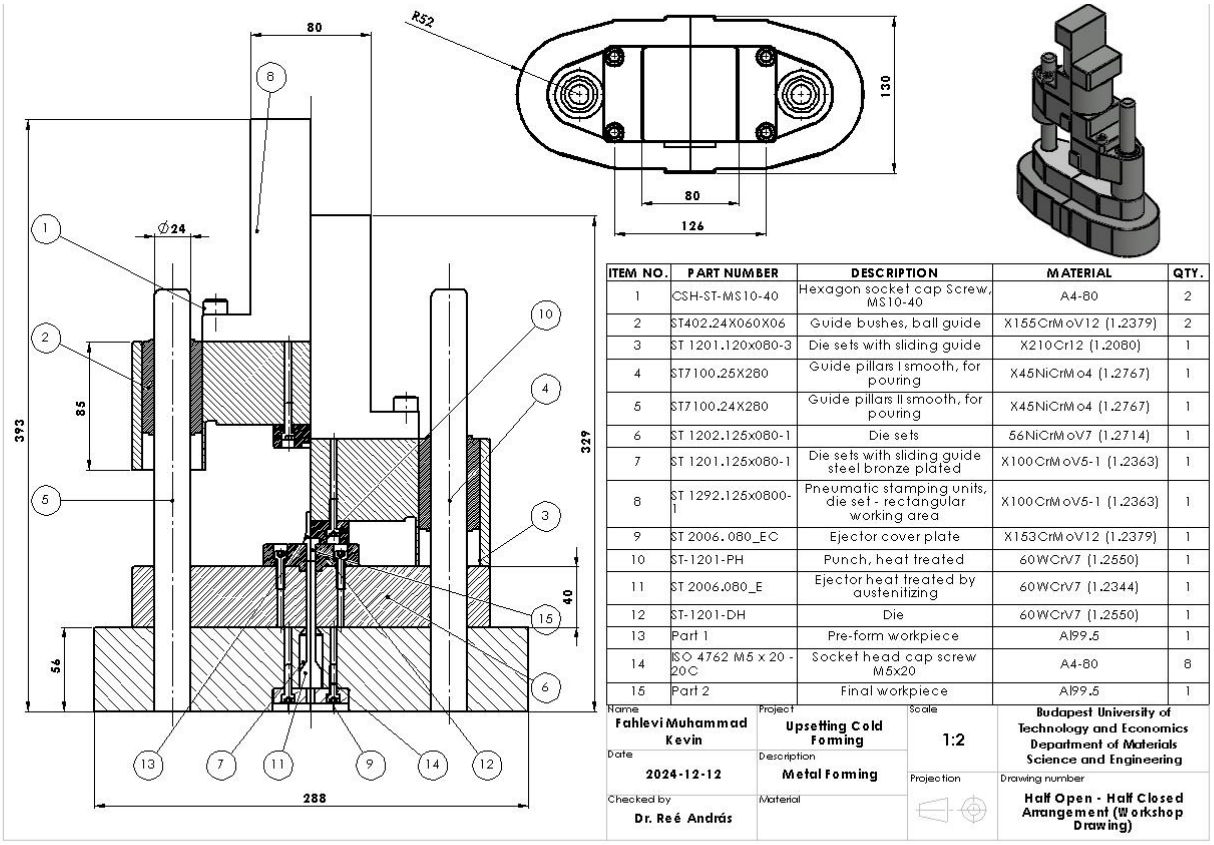


Full-open arrangement



Half open – half closed arrangement

8.3 Workshop CAD Drawing



ITEM NO.	PART NUMBER	DESCRIPTION	MATERIAL	QTY.
1	CSH-ST-MS10-40	Hexagon socket cap Screw, MS10-40	A4-80	2
2	ST402.24X060X06	Guide bushes, ball guide	X155CrMoV12 (1.2379)	2
3	ST 1201.120x080-3	Die sets with sliding guide	X210Cr12 (1.2080)	1
4	ST7100.25X280	Guide pillars I smooth, for pouring	X45NiCrMo4 (1.2767)	1
5	ST7100.24X280	Guide pillars II smooth, for pouring	X45NiCrMo4 (1.2767)	1
6	ST 1202.125x080-1	Die sets	56NiCrMoV7 (1.2714)	1
7	ST 1201.125x080-1	Die sets with sliding guide steel bronze plated	X100CrMoV5-1 (1.2363)	1
8	ST 1292.125x0800-1	Pneumatic stamping units, die set - rectangular working area	X100CrMoV5-1 (1.2363)	1
9	ST 2006. 080_EC	Ejector cover plate	X153CrMoV12 (1.2379)	1
10	ST-1201-PH	Punch, heat treated	60WCrV7 (1.2550)	1
11	ST 2006.080_E	Ejector heat treated by austenitizing	60WCrV7 (1.2344)	1
12	ST-1201-DH	Die	60WCrV7 (1.2550)	1
13	Part 1	Pre-form workpiece	Al99.5	1
14	ISO 4762 M5 x 20 - 20C	Socket head cap screw M5x20	A4-80	8
15	Part 2	Final workpiece	Al99.5	1

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   Upsetting: What It Is And How To Do It Right (blacksmithscompany.org)
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   ENAW-Al99.5 / ENAW-1050A - SteelNumber - Aluminium equivalent, chemical composition, properties
3. Upset Forging
   Upset forging | SpringerLink
4. 60WCrV7 Cold-Work Tool Steel Properties
   https://www.steel-grades.com/Steel-Grades/Tool-Steel-And-Hard-Alloy/60/598/DIN-60WCrV7.pdf
5. Heat Treatment Processes of 60WCrV7 Tool Steel
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