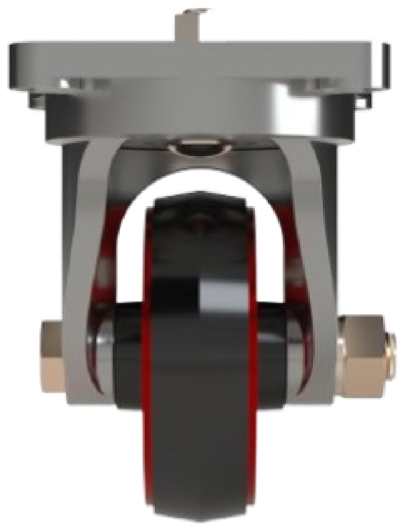
WHEEL FOR TROLLEYS

UNIVERSITÀ DEGLI STUDI DI PISA

INGEGNERIA PER IL DESIGN INDUSTRIALE

Mechanical Technology



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SUMMARY

INTRODUCTION

This project aims to examine and study **the various production processes**, selecting those most suitable for the manufacture of our components.

The assembly we have chosen for this process is a **non-steering rear wheel for a trolley**.

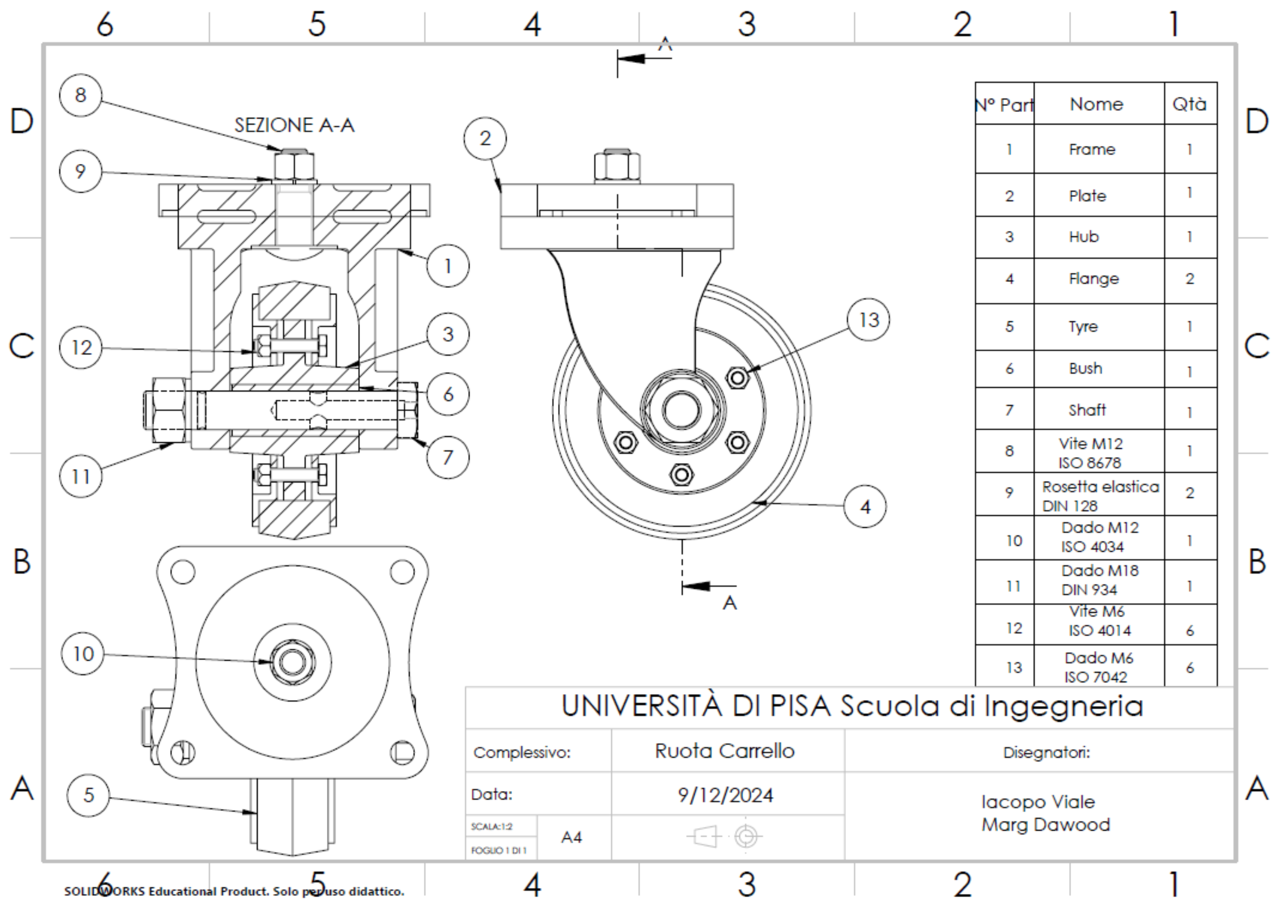


Figure 1: technical drawing of the "Trolley Wheel" assembly"

The **components** we analyzed, and the related **manufacturing processes,** are:

- (n° 1) Frame: casting process
- (n° 2) Plate: metal forming
- (n° 4) Flange: 3D printing
- (n° 7) Shaft: machining
- (n° 8) Vite M12 ISO 8678: welding

As a **scenario**, we assumed that we would receive an **order for 140 wheels** to be used in the construction of 70 service trolleys for university laboratories and workshops.

SOFTWARE USED

The **software programs** we used for this project are **three**:

- **Solidworks**: for 3D modeling and technical drawings
- **Inspire Cast 2025**: for the casting analysis
- **Snapmaker Luban**: to create the file we used for 3D printing

CASTING PROCESS

CHOOSING THE PIECE

The component of the wheel that we decided to manufacture through the casting process is the **Frame**, part **number 1**.

Considering the production batch, **140 pieces** need to be manufactured.

Figure 2: 3D model of the "Frame"

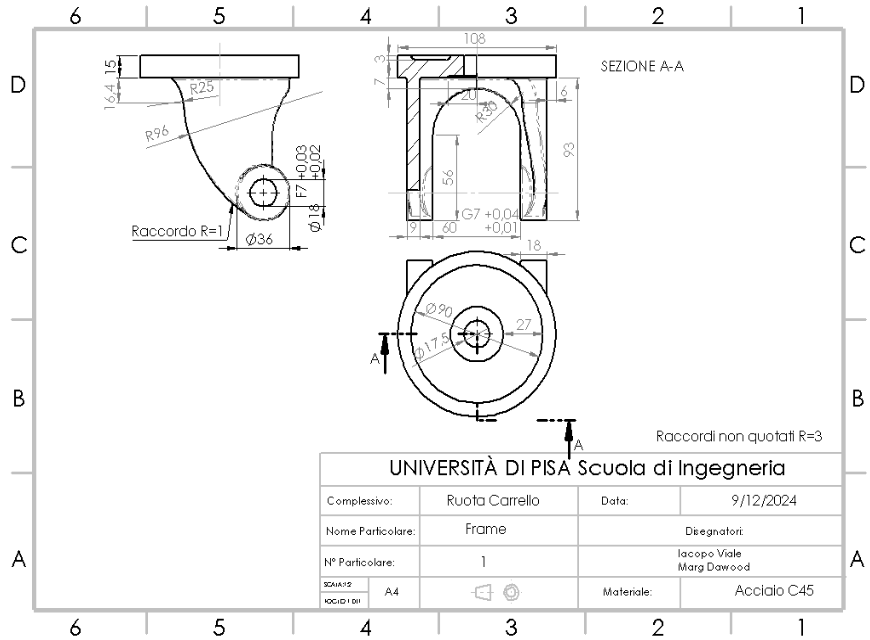


Figure 3: technical drawing of the "Frame"

MATERIAL SELECTION

The materials commonly used for this type of part are steel and aluminum.

We analyzed the operating context of trolleys that feature our type of wheels as components, which must withstand **heavy loads and impacts**. These conditions led us to select **steel** as our material, as it is more resistant than aluminum.

At this stage, we sought to determine whether alloy steels or non-alloy steels would be more suitable for our needs. Since **non-alloy steels** are preferable for foundry use, have lower costs, are readily available on the market, and still offer excellent mechanical properties, we decided to select our material within this category.

Therefore, we chose the **C45 steel** (non-alloyed according to the EN10020 standard) for these reasons:

- Excellent machinability
- Good castability
- Good mechanical strength
- Uniform cooling
- Low tendency to crack
- Can undergo heat treatments

- Widely available (a positive factor because there are many standards and the mechanical values are well established)

The cost of scrap steel is approximately **0.80€/kg,** and the **density** of this material is **7,850 kg/m³**.

Below is the technical **datasheet** of the material:

STEELMASTER
TRECLESS SOLUTIONS

Azienda con Sistema di Gestione della Qualità certificato UNI EN ISO 9001

C45

ACCIAI DA COSTRUZIONI

COMPOSIZIONE CHIMICA										
C	Si	Mn	Cr	Mo	Ni	W	Ti	Al	Co	V
0,50	0,35	0,80	-	-	-	-	-	-	-	-

IDENTIFICAZIONE COMPARATIVA

WERKSTOFF .NR 1.1730 - EN/DIN C45

PROPRIETÀ

L'acciaio c45 è un acciaio speciale che presenta un buon compromesso tra resistenza e tenacità. Particolarmente adatto per tempre superficiali con valori di durezza nelle zone così trattate di circa 57 HRC dopo distensione a 180 °C.

IMPIEGHI

Utilizzato nel settore meccanico per la costruzione di alberi, manovelle, chiavette, perni, aste, semiassi.

STATO DI FORNITURA Naturale

TRATTAMENTI TERMICI

Ricottura isotermica:
- riscaldamento a 820 ÷ 860 °C;
- raffreddamento in aria. Durezza massima: 163÷217 HB

Tempra:
- austenitizzazione a 820 ÷ 840 °C
- raffreddamento in acqua

Rinvenimento:
Nell'intervallo di temperatura compreso fra 550 ÷ 650 °C

CARATTERISTICHE MECCANICHE

Stato	Saggio Ø mm.	Re min. N/mm²	Rm N/mm²	A min. %	KCU min. J
	≤ 16	510	730÷870	14	20
Bonificato	16÷40	460	690÷830	15	17,5
	40÷100	410	640÷780	16	15
Normalizzato	16÷100	335	590÷740	17	-

Steelmaster s.r.l.
Via Enrico Mattei,
12/14 20010 Mesero (MI)

www.steelmaster.it
sales@steelmaster.it
Tel. 02.9015485

Le informazioni e i dati riportati sono indicativi, il nostro ufficio tecnico è a disposizione per ulteriori chiarimenti in base all' applicazione scelta.

Figure 4: technical datasheet of C45 steel

SELECTION OF CASTING METHOD

To determine the most suitable forming method, we first considered the client's requested quantity: 140 pieces.

This order falls within the small-to-medium batch range, which (as will be detailed in the "costs" section) allows for effective amortization of expenses related to sand casting, including flasks, molding sand, and pattern plates.

Had we chosen "shell casting," we would have had too few pieces to amortize the cost of the molds; indeed, this method is typically selected for large production runs. Furthermore, our part has a complex shape, which led us to also consider "investment casting" because of its ability to produce highly intricate geometries.

For reasons like those we explained for the "shell casting", we decided not to choose the "investment casting" and to continue the design using **the sand casting method**.

SAND SELECTION

We did some research and based on that we selected three types of sand, green, chromite and olivine, and compared them to determine which was most suitable for our needs.

Although green sand is the cheapest, it can be reused for multiple cycles and it's suitable for castings of similar size to ours. We discarded it because the maximum operating temperature is too close to the melting point of our steel.

On the other hand, both chromite and olivine sands met our requirements (excellent permeability, low thermal expansion, higher maximum operating temperature, excellent refractoriness and reusability), so we decided to choose based on which was less expensive.

Our final choice, therefore, is **olivine sand (Mg_2SiO_4)**, characterized by a **density** of **3300Kg/m^3** ("*Ore-Met Olivina Sands*") and, assuming that our company carries out other castings beyond this project and thus requires tons of sand, a wholesale cost of approximately **0,25€/Kg**.

CASTING DESIGN

SELECTION OF THE PARTING PLANE

To select the most efficient **parting plane** for our casting, we focused on minimizing undercuts and, given that constraint, choosing the simplest possible geometry

After various considerations and trials using SolidWorks, we arrived at this decision: a plane that divides the part into two symmetrical halves and minimizes undercuts.

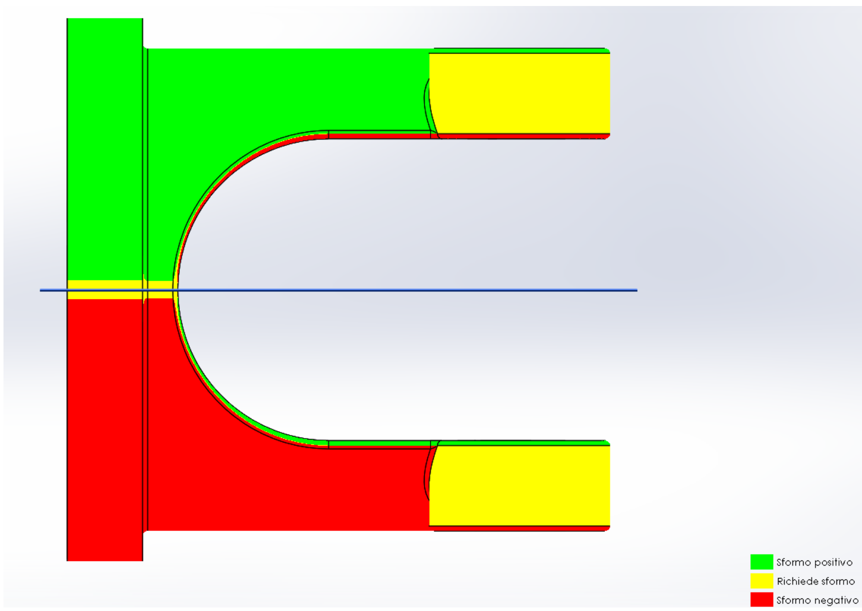


Figure 5: side view of the selected parting plane

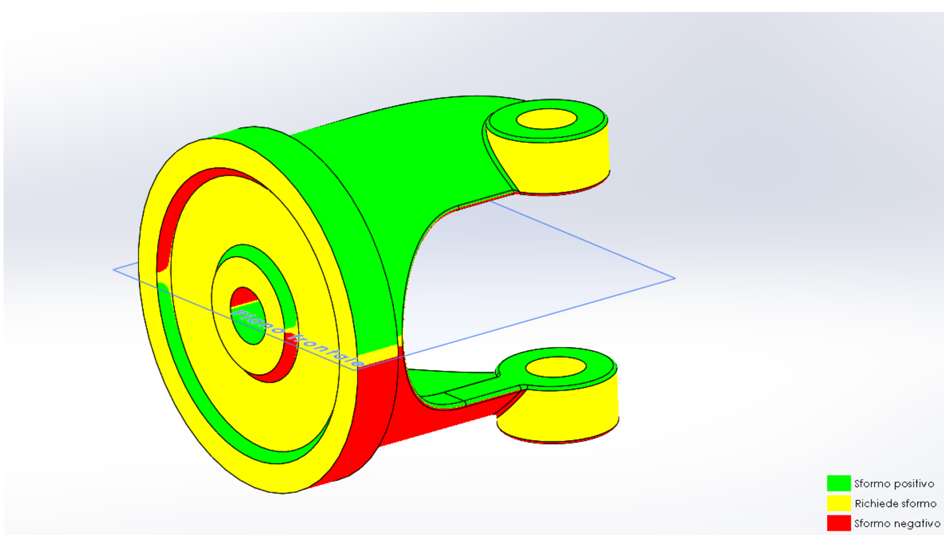


Figure 6: view of the selected parting plane

RISERS

At this stage, we incorporated **risers** into the initial part.

We first identified the **areas** requiring them (all zones with tolerances, the holes, the upper region where assembly takes place and the circular crowns around the holes) and then we determined which **dimensions were critical** and which were not.

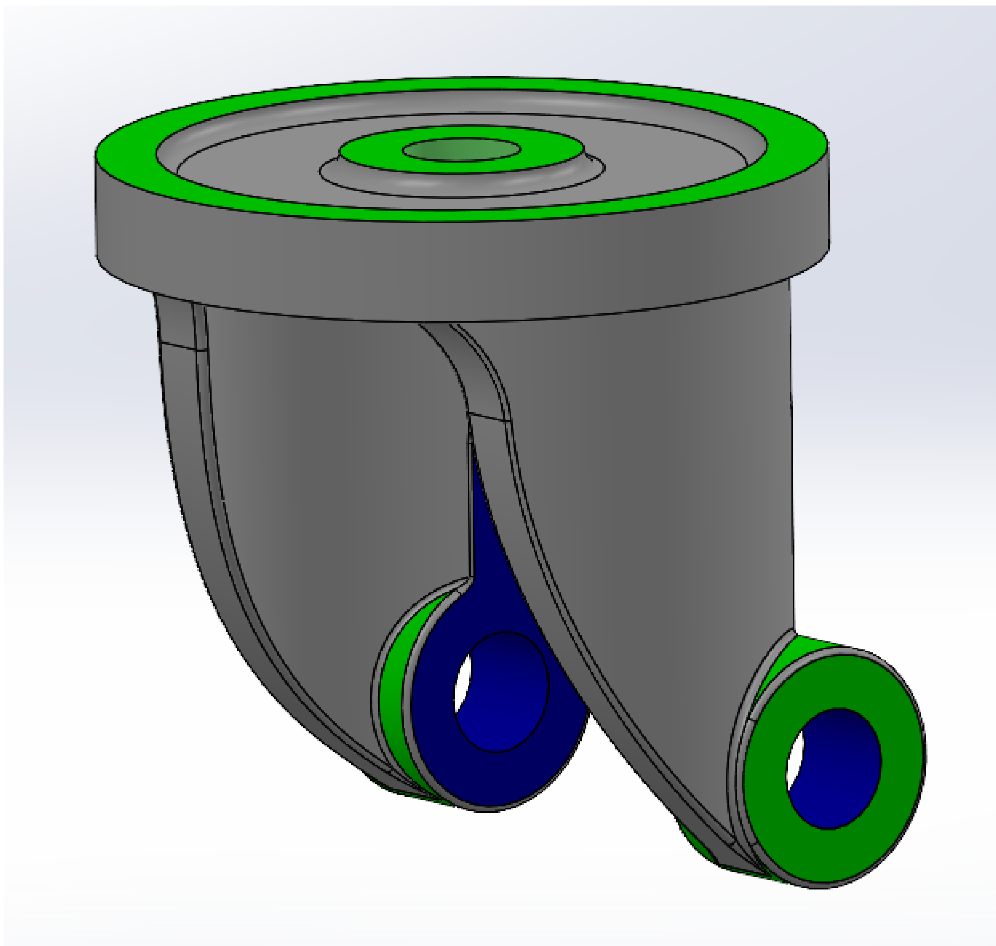


Figura 7: surface risers

Not critical | **Critical**

Knowing the dimensions of our piece, the material, the casting method and having differentiated the zones for risers, we applied the recommended dimension from the tables in the book "*Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti*".

Quote nominali di riferimento (mm)	MASSIMA DIMENSIONE DEL PEZZO (mm)		
	≤250	250 ÷ 1000	≥1000
≤ 40	4	4	5
40 ÷ 65	4	4	5
65 ÷ 100	4	4	5
100 ÷ 160	4	5	5
160 ÷ 250	6	6	7
250 ÷ 400	–	6,5	7
400 ÷ 630	–	7	8
630 ÷ 1000	–	8	9

Il sovrametallo delle superficie di partenza si considera uguale a 3 mm per pezzi con dimensione massima ≤ 160 mm e uguale a 4 mm per pezzi con dimensione max >160 mm.

Table 1: Risers on the "non-critical" dimensions of steel castings for sand casting, "ANFOR"

Quote nominali di riferimento (mm)	MASSIMA DIMENSIONE DEL PEZZO (mm)		
	≤250	250 ÷ 1000	≥1000
≤ 40	6	6	8
40 ÷ 65	6	6	9
65 ÷ 100	6	7	10
100 ÷ 160	7	7	10
160 ÷ 250	8	8	10
250 ÷ 400	–	9	11
400 ÷ 630	–	10	12
630 ÷ 1000	–	11	14
1000 ÷ 1800	–	–	17
1800 ÷ 2500	–	–	20

Il sovrametallo della superficie di partenza si considera uguale a 4 mm.

Table 2: Risers on the "critical" dimensions of steel castings for sand casting, "ANFOR"

Using those information's in the modeling, we obtained the following piece:

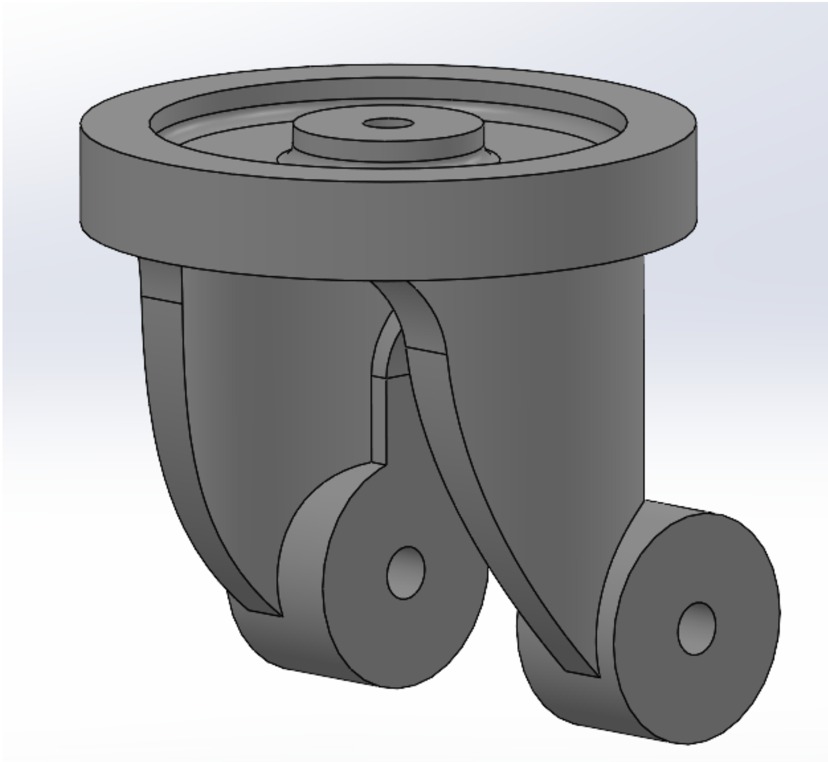


Figure 8: model of the "Frame" after the added risers

SHRINKAGE

During cooling (post-casting), the material contracts, so we had to scale our piece to ensure that the component would have the correct dimensions once cooled.

To determine the scaling factor, we again consulted the tables in the book "*Santochi*":

MATERIALI	RITIRO %		
	Getti piccoli	Getti medi	Getti grandi
Ghise grigie	1	0,85	0,7
Ghise malleabili	1,4	1	0,75
Ghise legate	1,3	1,05	0,35
Acciaio	2	1,5	1,2
Alluminio e leghe	1,6	1,4	1,3
Bronzi	1,4	1,2	1,2
Ottoni	1,8	1,6	1,4
Leghe di magnesio	1,4	1,3	1,1

Table 3: table of shrinkage values "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

As the relevant shrinkage coefficent is 2%, we scaled the part by a factor of **1,02**.

DRAFT ANGLES

To make the removal of the pattern easier, we added draft angles.

We chose the draft angles considering that the **pattern** material will be **wood**, therefore, we require draft angles of at least **2**°.

Valori indicativi dell'angolo di sformo	
Modelli in legno	1°-2°
Modelli metallici	30′
Portate d'anima verticali	10°-12°
Nervature sottili	1′-2′

Table 4: draft angle values "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

We did not apply draft angles to all surfaces, but only to the ones that required them; to do so, we used the "draft analysis" function available in the software "*SolidWorks*".

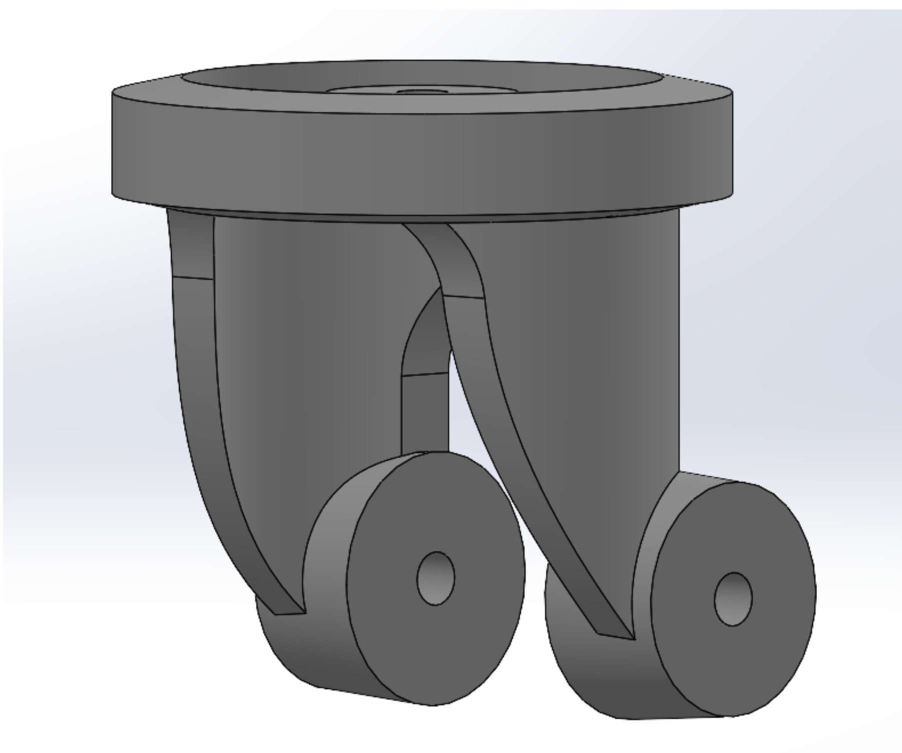


Figure 9: 3D model of the "Frame" after the added draft angles

FILLET RADII

At this stage of the design, all sharp corners are eliminated because they can act as stress concentrators, lead to cracks, and cause other issues. Appropriate fillet radii were added to address these concerns.

Based on excerpts from technical literature such as *"Principles of Metal Casting (Heine, Loper, Rosenthal)"* and *"Foseco Foundryman's Handbook"* as well as experience from previous university courses, internal corners should have fillets at least twice the size of external corners. For this reason, we used fillets of **1° for external** corners **and 3° for the internal** ones.

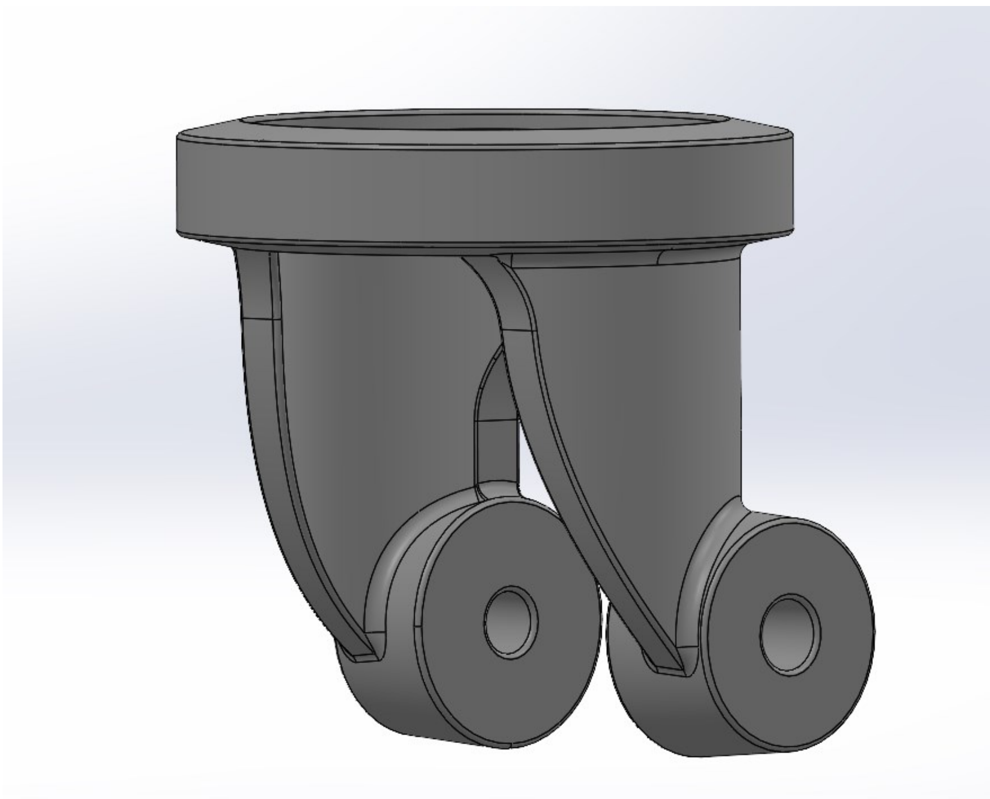


Figure 10: 3D model of the "Frame" after the added fillet radii)

DESIGN OF CORES

SAND

For the selection of the sand and other additives, we kept in mind some properties that this mixture should have:

- Good thermal resistance
- Mechanical strength at temperatures above 1600 °
- Excellent dimensional stability and accuracy
- Preferably, good ventilation

By researching and analyzing the characteristics of different types of sand, we focused mainly on "pre-coated sands" and "special ceramic sands".

Our final decision was to use **"pre-coated sand",** because it is ideal for complex geometries, it has a high heat resistance and generally has a lower density than the alternative.

As the base, we selected silica sand, while as the liquid binder and powdered additive, we used **Inotech 3000** (recommended for steel castings and for reducing porosity) and **Promotor WJ6500**.

The manufacturers recommend a composition of **96%** sand, **2%** binder, and **2%** promoter.

This mixture has a density of approximately **1590Kg/m^3** and a cost of about **0,20€/Kg.**

CORE MODELING AND CORE PRINTS

We planned to make **two cores** that interlock with each other: one insert for the upper countersink and another to fill the void between the two "cheeks" of the part.

Regarding the **core prints**, we extended the cylindrical sections of both cores, differentiating them according to core size: the central core has a core print of **50 mm**, while the insert (being smaller) has one of **30 mm**.

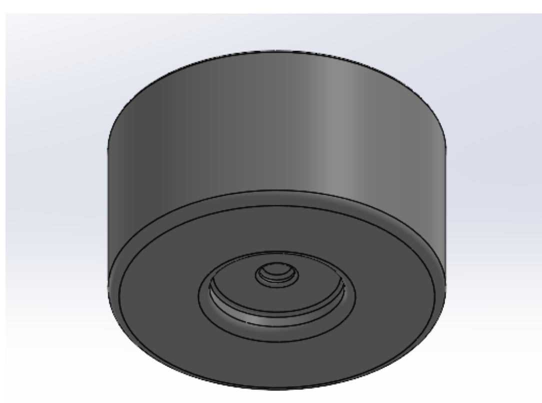


Figure 11: 3D model "Tassello"

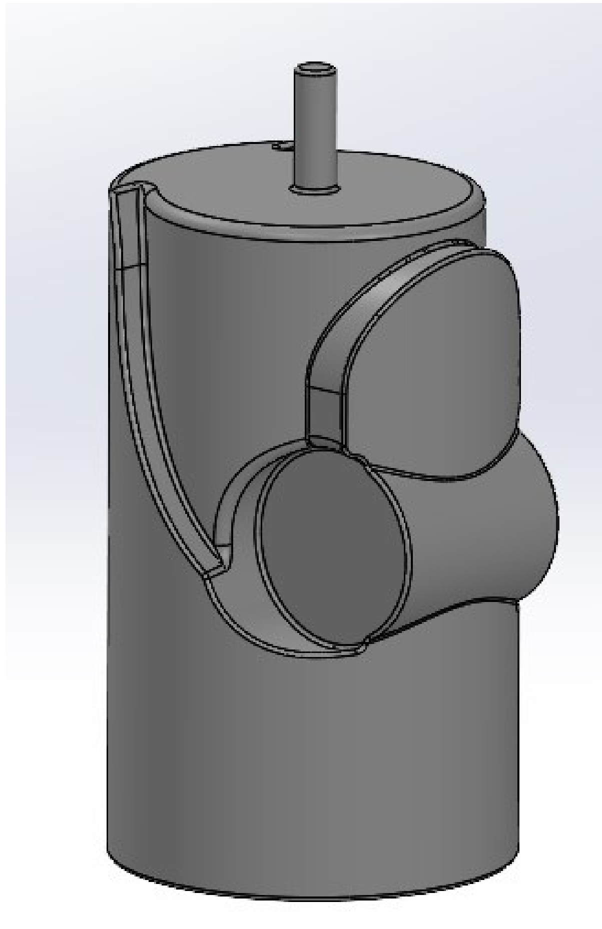


Figure 12: 3D model “Anima Centrale”

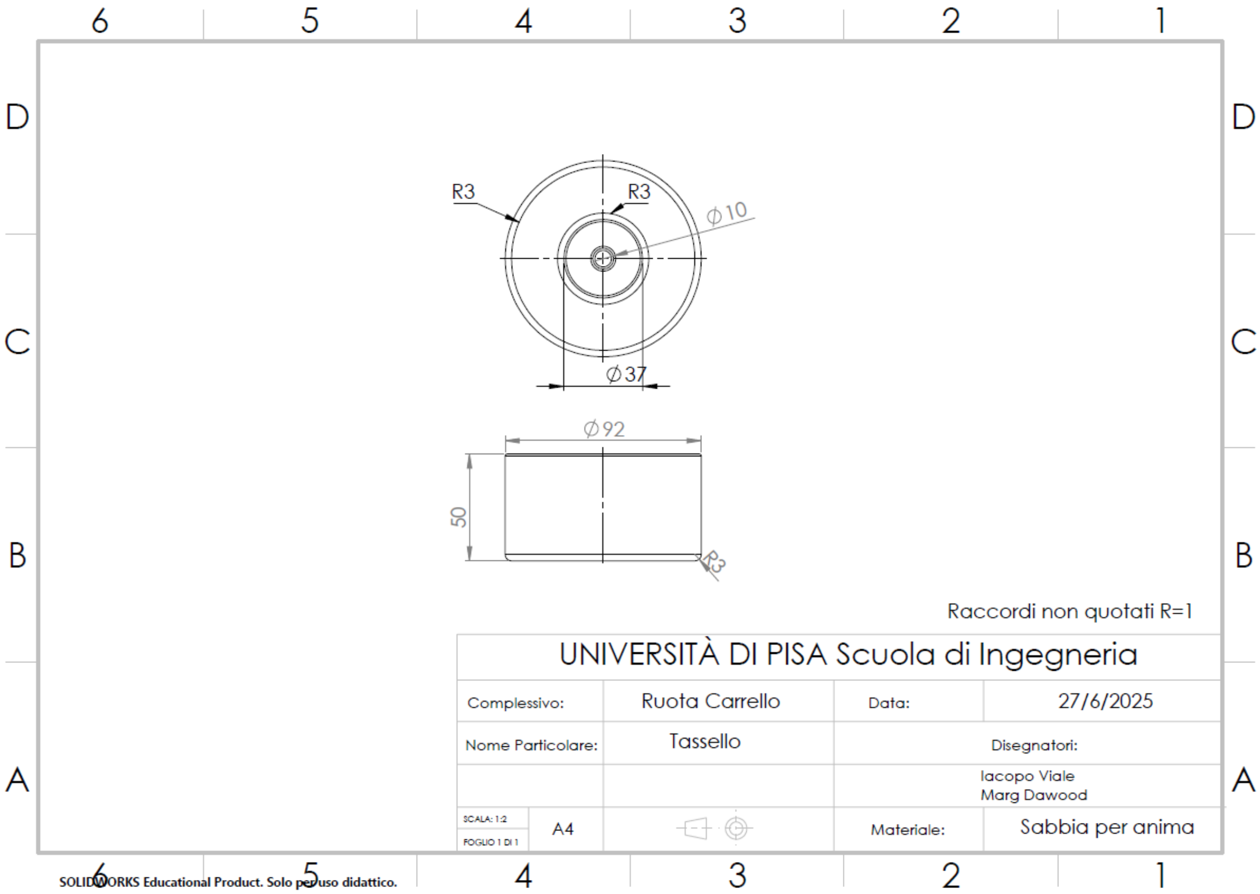


Figure 13: technical drawing "Tassello"

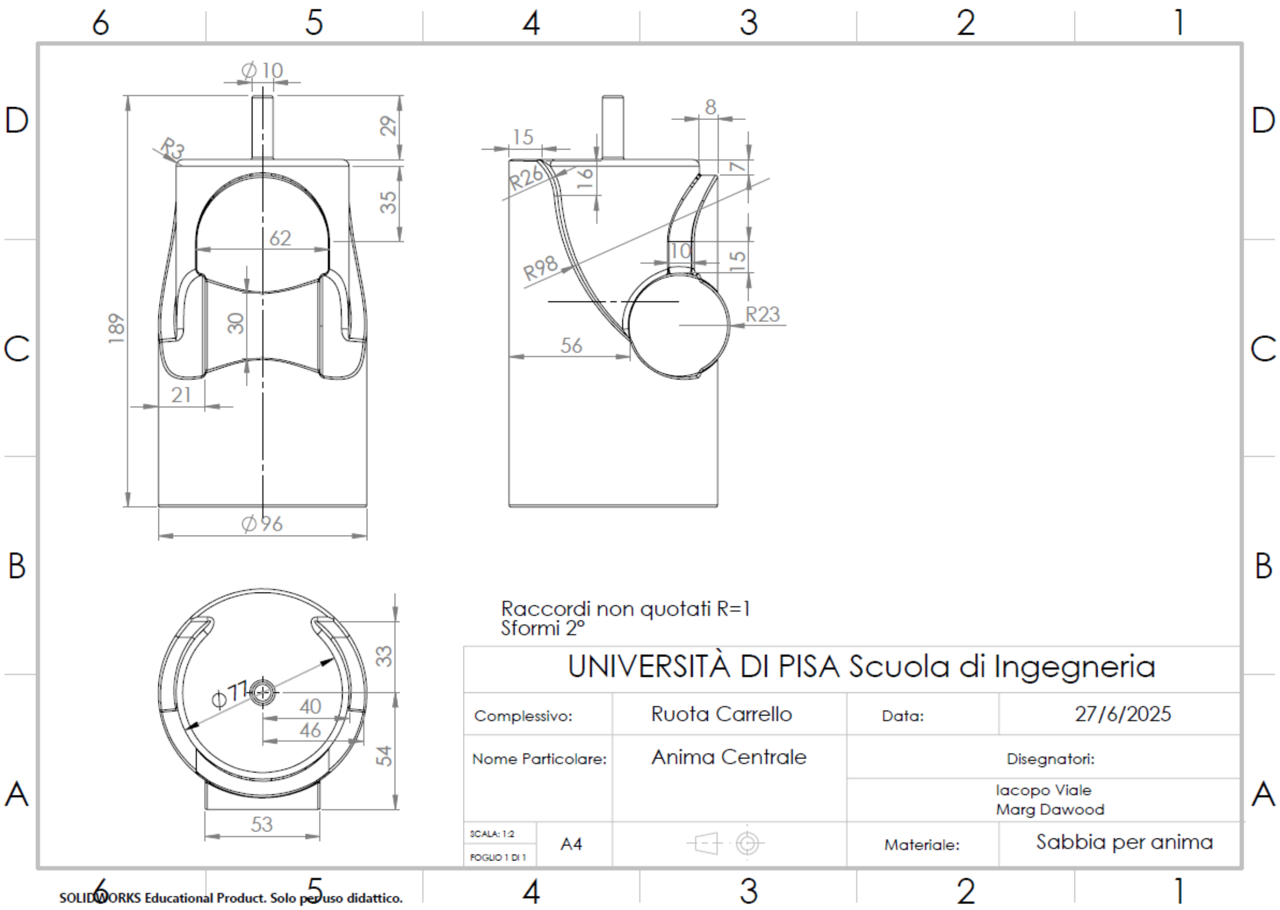


Figure 14: technical drawing "Anima Centrale"

COOLING

COOLING MODULI

Before calculating the cooling moduli, we divided our part based on geometric changes and symmetry.

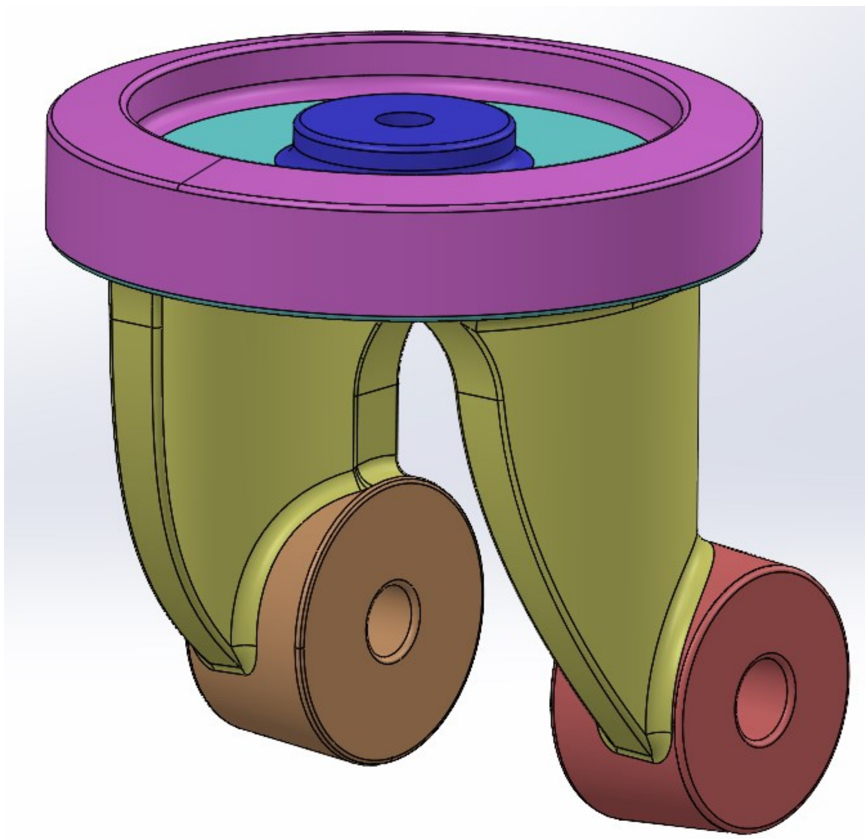


Figure 15: subdivision of cooling moduli

Since the volumes and the areas of these subdivisions were not easy to calculate, we used the “mass properties” and “measure” functions in “SolidWorks” to obtain these more precise results.

Below are the calculations of the cooling moduli in ascending order (with A_{common} referring to the surface area of the considered zone that is not in contact with the exterior):

- **M1** (**yellow** area):
  $V = 82801{,}63\ mm^3$
  $A_{total} = 38063{,}55\ mm^2$
  $A_{common} = 10915{,}64\ mm^2$

$A = A_{total} - A_{common} = 27147{,}91\ mm^2$
$M1 = V/A = 3{,}05\ mm$

- **M2** (**blue** area):
  $V = 7241{,}19\ mm^3$
  $A_{total} = 3565{,}74\ 50\ mm^2$
  $A_{common} = 1359{,}60\ mm^2$
  $A = A_{total} - A_{common} = 2206{,}14\ mm^2$
  $M2 = V/A = 3{,}28\ mm$

- **M3** (**pink** area):
  $V = 37557{,}64\ mm^3$
  $A_{total} = 15380{,}50\ mm^2$
  $A_{common} = 5213{,}46\ mm^2$
  $A = A_{total} - A_{common} = 10167{,}04\ mm^2$
  $M3 = V/A = 3{,}69\ mm$

- **M4** (**red** and **orange** area):
  Since the two "cylinders" are identical, the modulii are equal.
  The measurements of a "cylinder" are shown below.
  $V = 42954{,}82\ mm^3$
  $A_{total} = 7875{,}09\ mm^2$
  $A_{common} = 2407{,}23\ mm^2$
  $A = A_{total} - A_{common} = 5467{,}86\ mm^2$
  $M3 = V/A = 7{,}86\ mm$

- **M5** (**light blue**area):
  $V = 133642{,}33\ mm^3$
  $A_{total} = 26661{,}33\ mm^2$
  $A_{common} = 12674{,}24\ mm^2$
  $A = A_{total} - A_{common} = 13987{,}09\ mm^2$
  $M3 = V/A = 9{,}55\ mm$

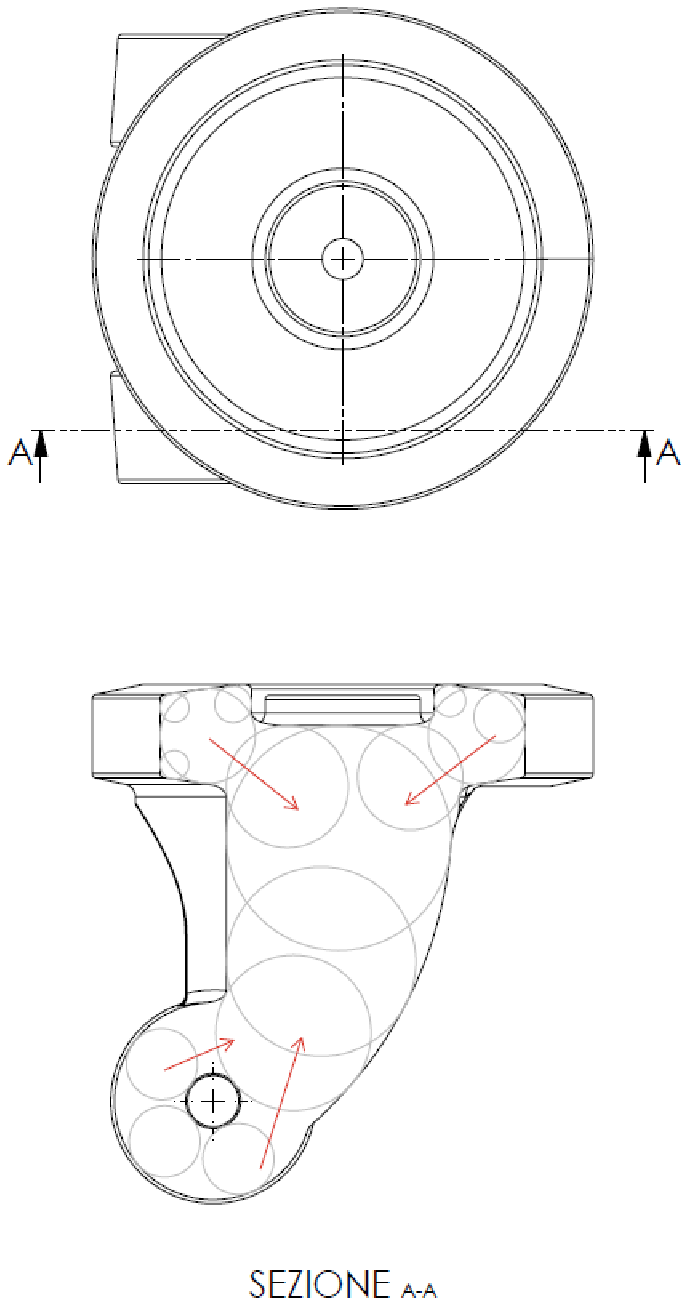


Figure 16: representation of "Heuvers' circles"

FEEDERS DESIGN

The **design of the feeders** can be divided into two parts:

- **The design**:

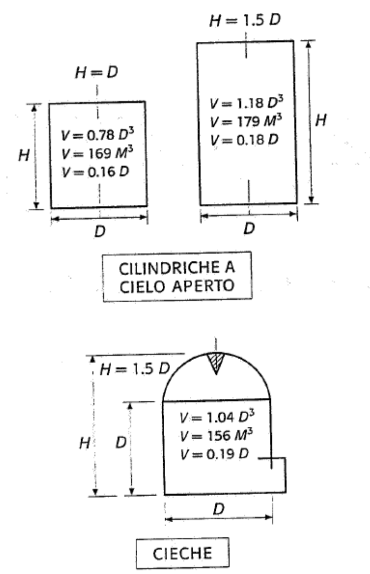
  We started by analyzing the position of the cooling modules, noting that the distribution was not linear.

  At this point, we began sizing possible feeders (using the formulas covered in class and in the book *"Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"*) to be placed in zones M4 and M5, both in the "open-top" and "blind" versions.

  After calculating both cases for both feeders, we observed that the feeder necks, in the case of blind feeders, would have been larger than the attachment point itself. Therefore, we proceeded with the design of **open-top feeders**.

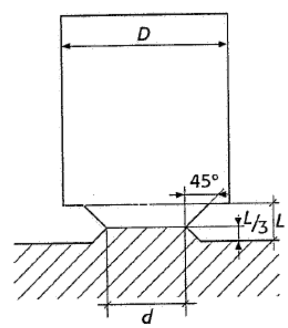
  Below are the calculations for the feeders in this version.

  (With M_m referring to the feeder modulus).



b) Materozze a cielo aperto

Materiale	d	L
Acciaio	0.40 D	0.14-0.18 D
Ghisa	0.66 D	0.14-0.18 D
Leghe di rame	0.66 D	0.25 D
Leghe leggere	0.75 D	0.18 D



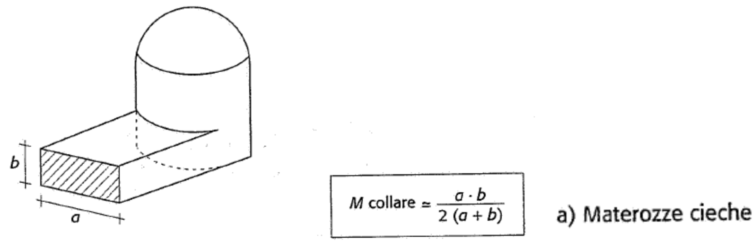


Figure 17: feeder sizing "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

- **Feeder in M5:**
  M_m = M4*1,2 = 11,46 mm
  V = 179M_m^3 = 269405,76 mm^3
  D = $\sqrt[3]{(V/1,18)}$ = 61,12 mm
  H = 1,5*D = 91,68 mm
  d = 0,4*D = 24,45 mm
  L = 0,18*D = 11,00 mm

- **Feeder in M4:**
  M_m = M5*1,2 = 9,43 mm
  V = 179M_m^3 = 150102,56 mm^3
  D = $\sqrt[3]{(V/1,18)}$ = 50,29 mm
  H = 1,5*D = 75,44 mm
  d = 0,4*D = 20,12 mm
  L = 0,18*D = 9,05 mm

- **Part with InspireCast 2025**:

  At this point, we have verified that our hypotheses are right (number, position and sizing of the feeders), through the functions in "*InspireCast*".

  The most critical parameter to be met was porosity: we carried out numerous trials until we found the solution that provided the lowest possible **porosity**, at a value of **5%.** After all these checks, we concluded that the feeder in M5 is sufficient and ensures minimum porosity.

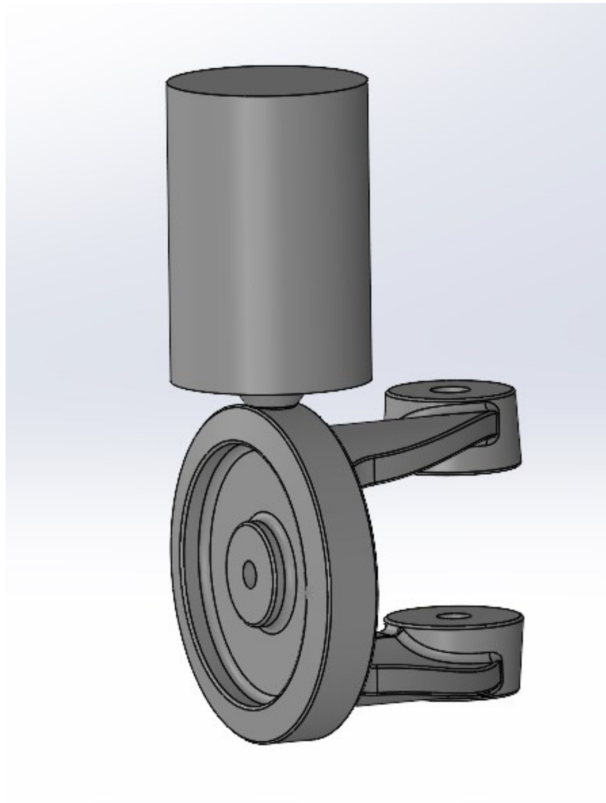


Figure 18: 3D model “Frame” with the added feeder

GATING SYSTEM DESIGN

TESTS

In the following sections, we report only the calculations of the final gating system and all the decisions we made.

We did not design a single system and assume it to be correct; instead, we carried out several trials, varying parameters such as type (pressurized and non-pressurized), number of ingates (circular, triangular, trapezoidal), and others.

The systems that were discarded were rejected for two reasons: either the melt solidified before filling was complete, or porosity levels at 5% were too high.

Below are some screenshots of the studies we conducted with the “*InspireCast 2025*” software to verify the correctness of the systems:

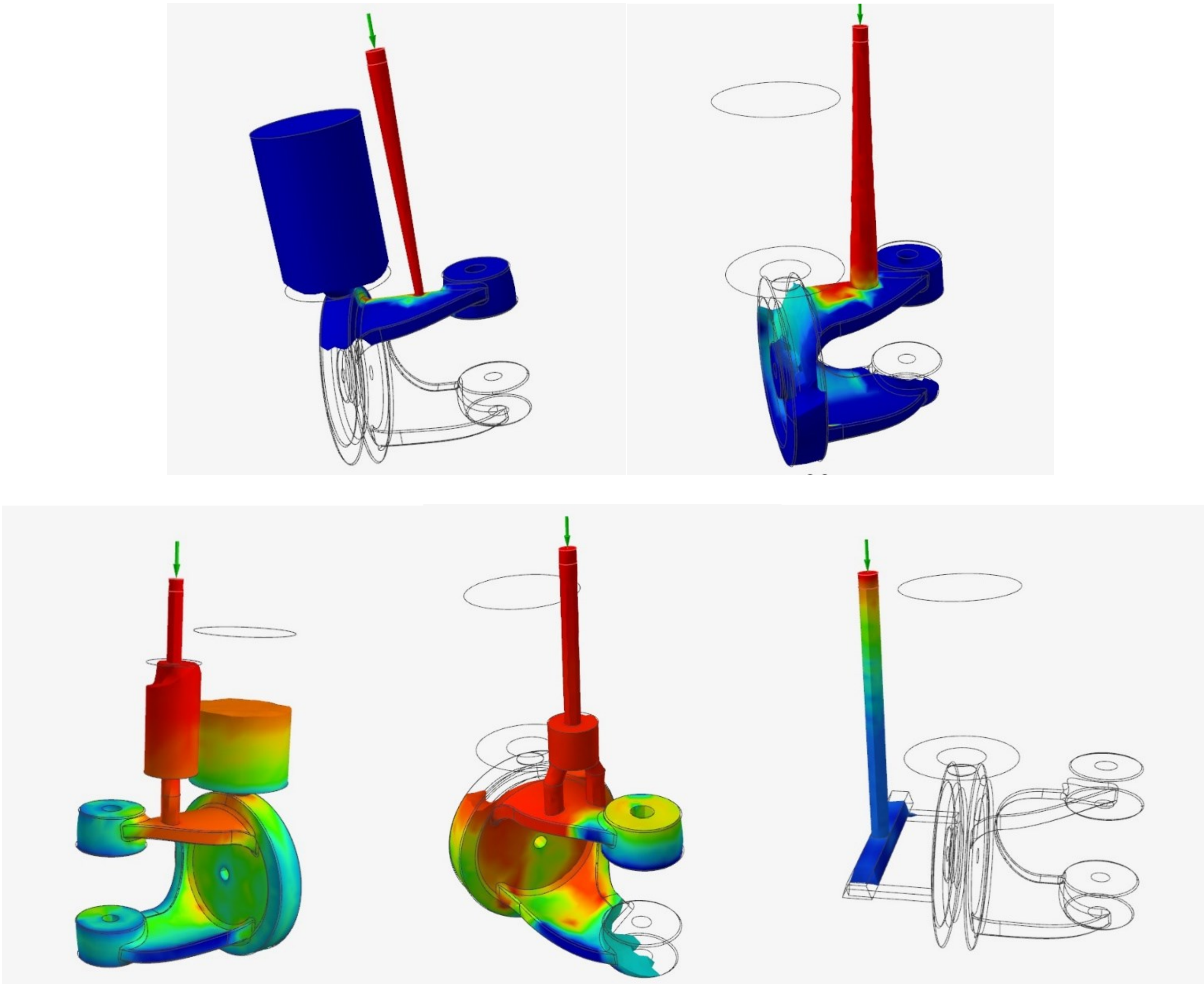


Figure 19: five different gating systems that did not work

TYPE

First, we designed the various gating systems for both the "pressurized" and "non-pressurized" cases.

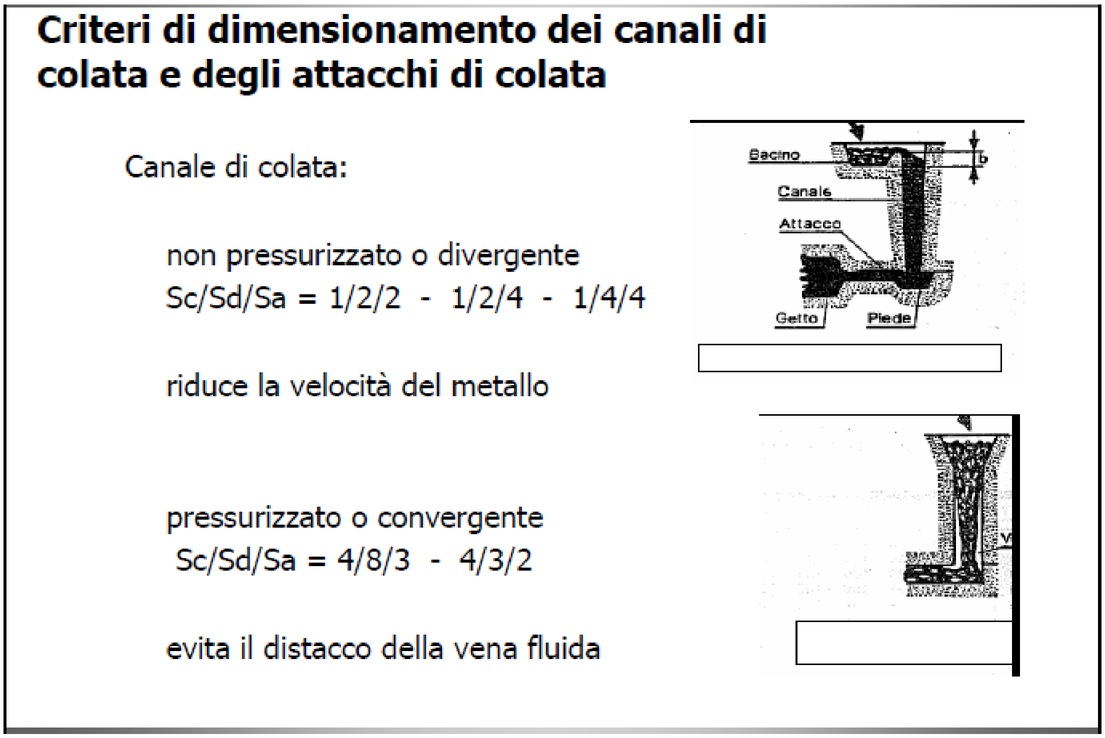


Figure 20: sizing of gating channels and ingates, University of Trieste, "Le Lavorazioni Per Fusione"

Although the "non-pressurized" system was the most suitable for our setup (due to its low outflow velocity, which reduces turbulence and promotes laminar flow along the walls), the channel sections were too small, resulting in systems that could not complete filling during the simulation.

Therefore, we began calculating the various sections according to the sizing of the **"pressurized system"** shown in the table above.

Although we considered the other system better, this one also has its advantages: it prevents the flow from separating from the walls, preventing the air from flowing within the casting.

GENERAL DIMENSIONS

$V_{tot} = V_{piece} + V_{feeder} = 752477{,}36\ mm^3$ (taken from "*SolidWorks*")

Casting weight: $G = V_{tot} * \rho = 5{,}91 Kg$ ($\rho = 7{,}85*10^{-6}\ Kg/mm^3$)

Pouring time: $T = 3{,}2 * \sqrt{G} = 7{,}77$ s

Flow rate: $K = G/T = 0{,}76$ Kg/s

Pouring head: $h = 173{,}00$ mm (measured with "*SolidWorks*", knowing the point from which I pour)

Fluid speed: $v = \sqrt{(2*g*h)} = 1842{,}35$ mm/s

Section of the ingates: $S_a = K / (v * \rho) = 52{,}55\ mm^2$

INGATES

Section of the ingates: $S_a = 52{,}55\ mm^2$

Using two ingates with a circular cross-section, their radii are:

$R_a = \sqrt{(S_a / 2*\pi)} = 2{,}89$ mm

GATING CHANNEL

Section of the gating channel: $S_c = S_a*2 = 105{,}1\ mm^2$

Using an ingate with a circular cross-section, the radius is:

$R_c = \sqrt{(S_c / \pi)} = 5{,}78$ mm

DISTRIBUTION CHANNEL

Section of the distribution channel: $S_d = S_a*1{,}5 = 78{,}83\ mm^2$

Using an ingate with a trapezoidal cross-section:

$b = 2*R_c$

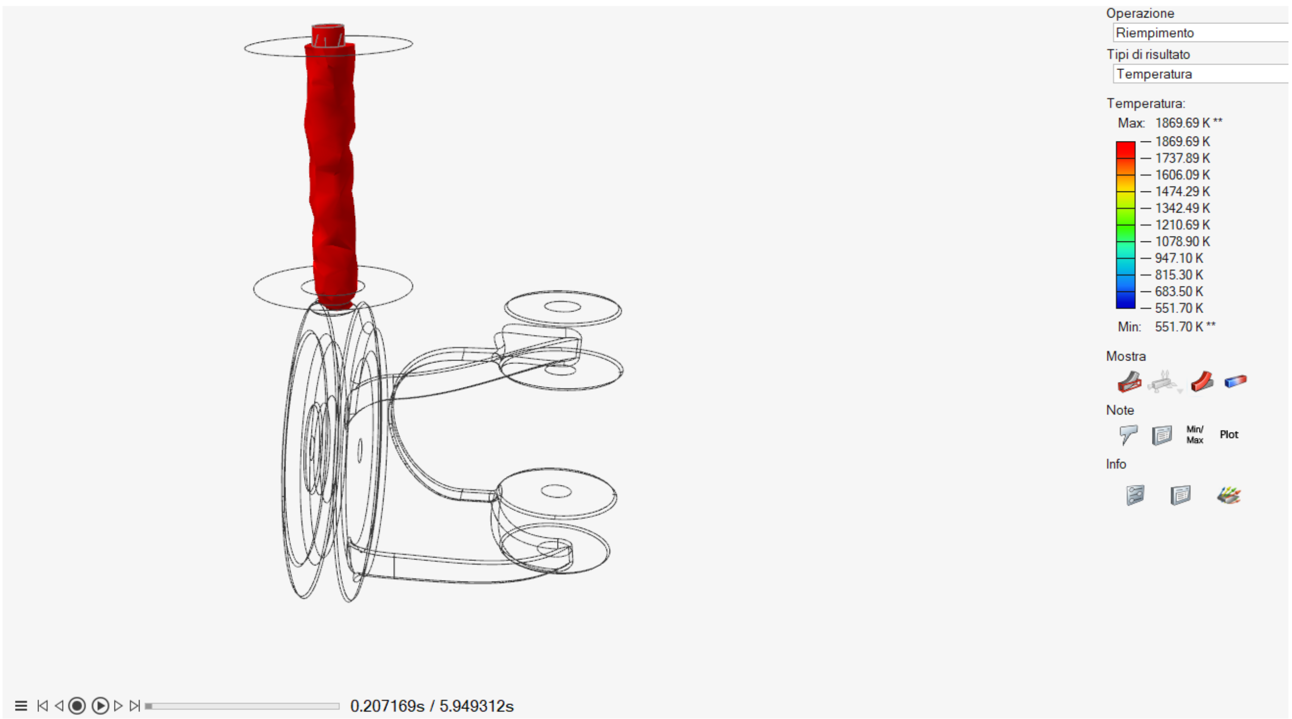
$B = (3/2) * b = 3*R_c$

$S_d = (b+B) * h/2 \rightarrow h = 8{,}76$ mm

FINAL SYSTEM

After all the calculations and trials with the various systems (which should now clarify the previous discussion regarding the 'non-pressurized' system), we observed that the system achieving full filling and minimal porosity is the one obtained by **pouring directly into the feeder**.

FILLING TEMPERATURE




Operazione
Riempimento
Tipi di risultato
Temperatura
Temperatura:
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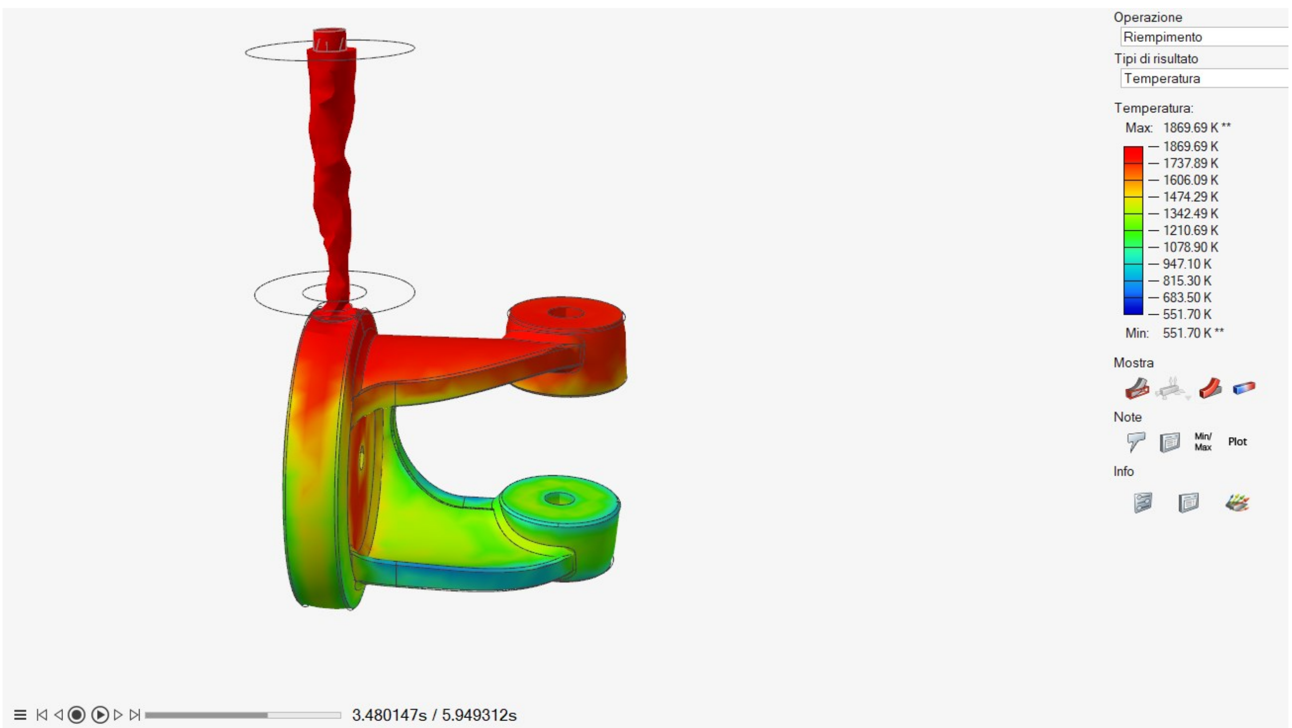
1869.69 K
1737.89 K
1606.09 K
1474.29 K
1342.49 K
1210.69 K
1078.90 K
947.10 K
815.30 K
683.50 K
551.70 K
Min: 551.70 K **
Mostra
Note
Min/ Max
Plot
Info
1.663514s / 5.949312s


Operazione
Riempimento
Tipi di risultato
Temperatura
Temperatura:
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1342.49 K
1210.69 K
1078.90 K
947.10 K
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551.70 K
Min: 551.70 K **
Mostra
Note
Min/ Max
Plot
Info
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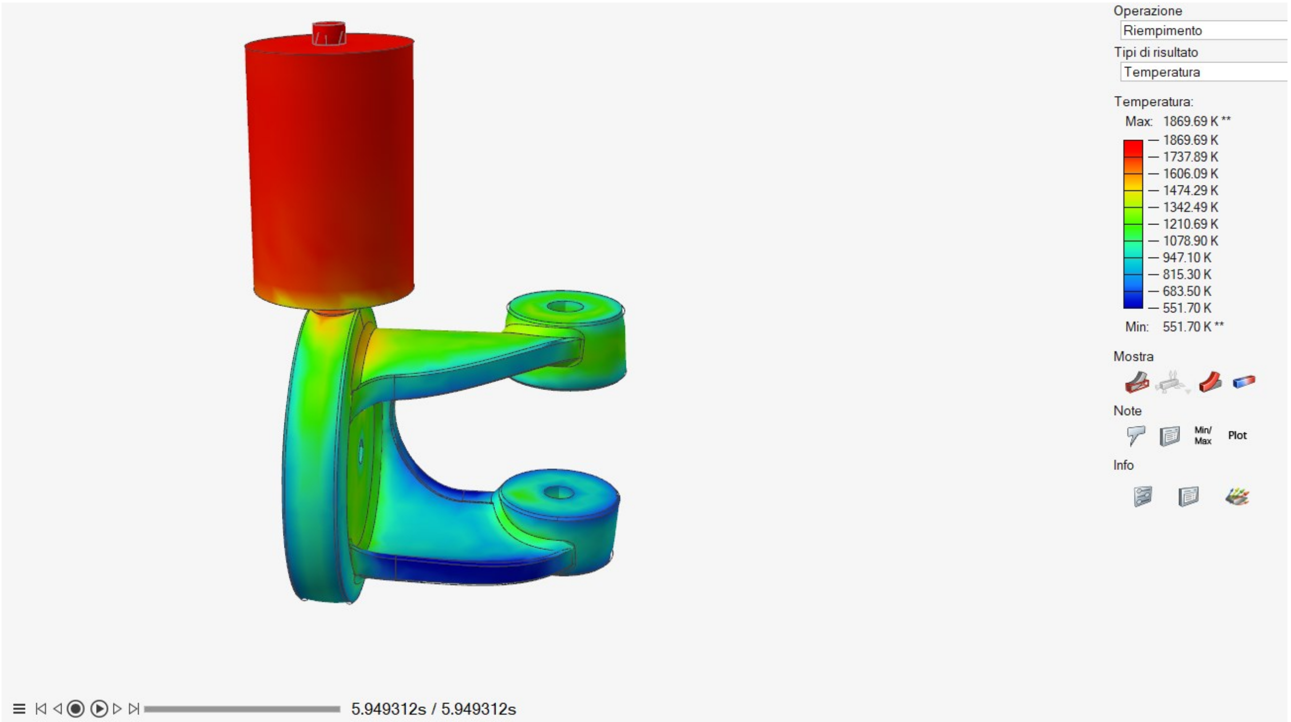
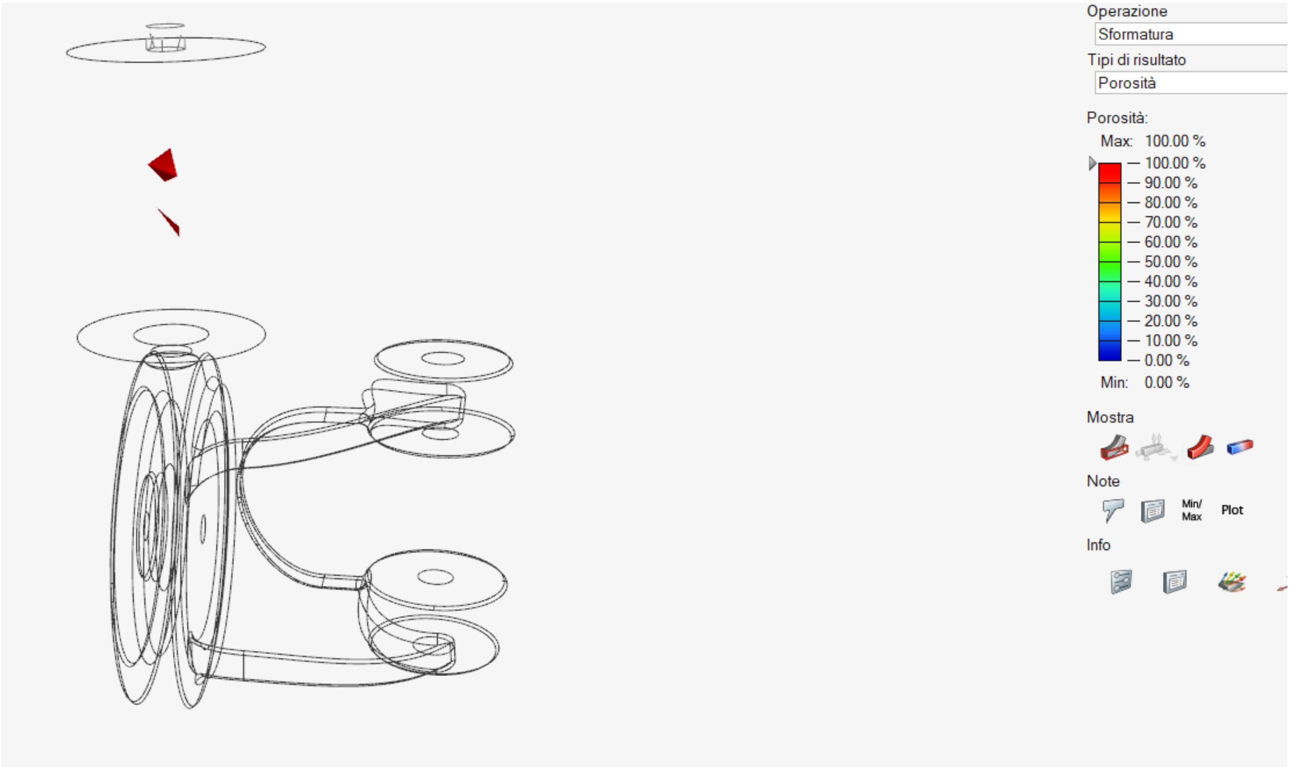


Figure 21: four pictures showing the temperature during the filling process

POROSITY


Operazione
Sformatura
Tipi di risultato
Porosità
Porosità:
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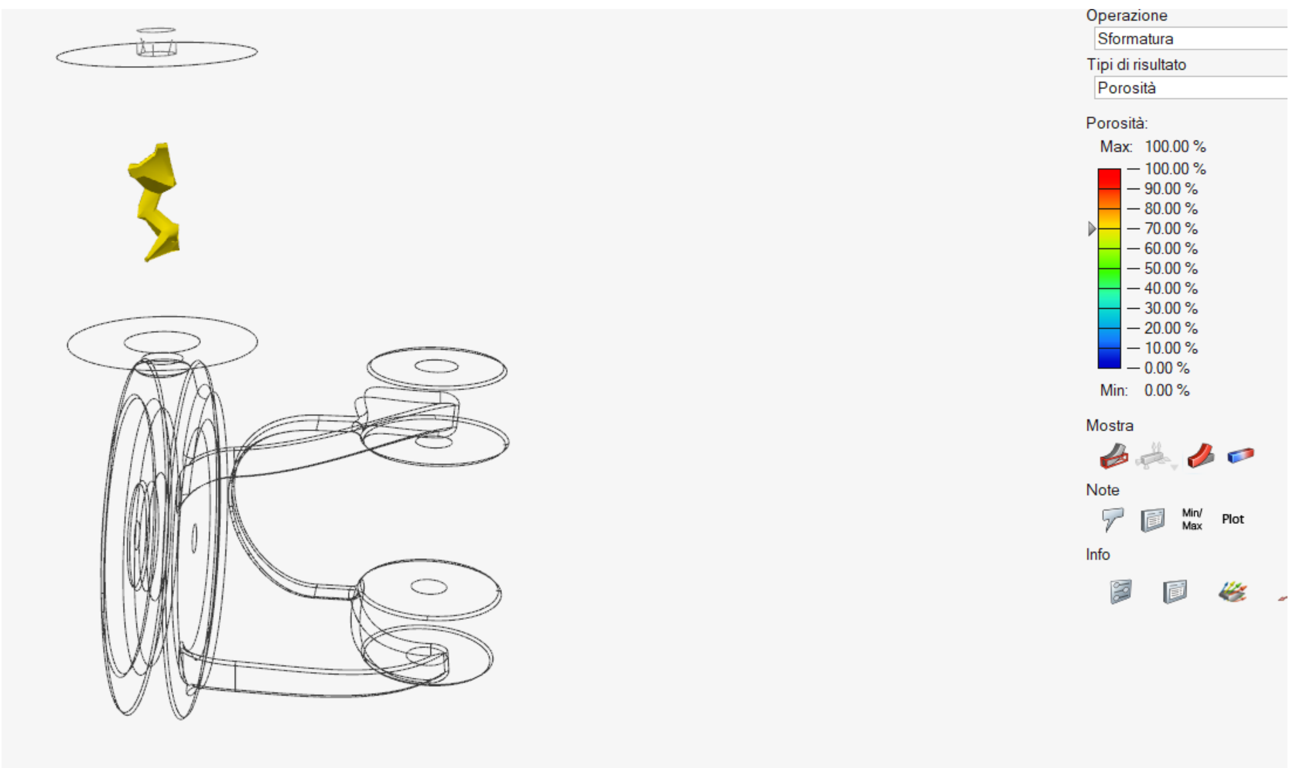
100.00 %
90.00 %
80.00 %
70.00 %
60.00 %
50.00 %
40.00 %
30.00 %
20.00 %
10.00 %
0.00 %
Min: 0.00 %
Mostra
Note
Min/ Max
Plot
Info


Operazione
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Min/ Max
Plot
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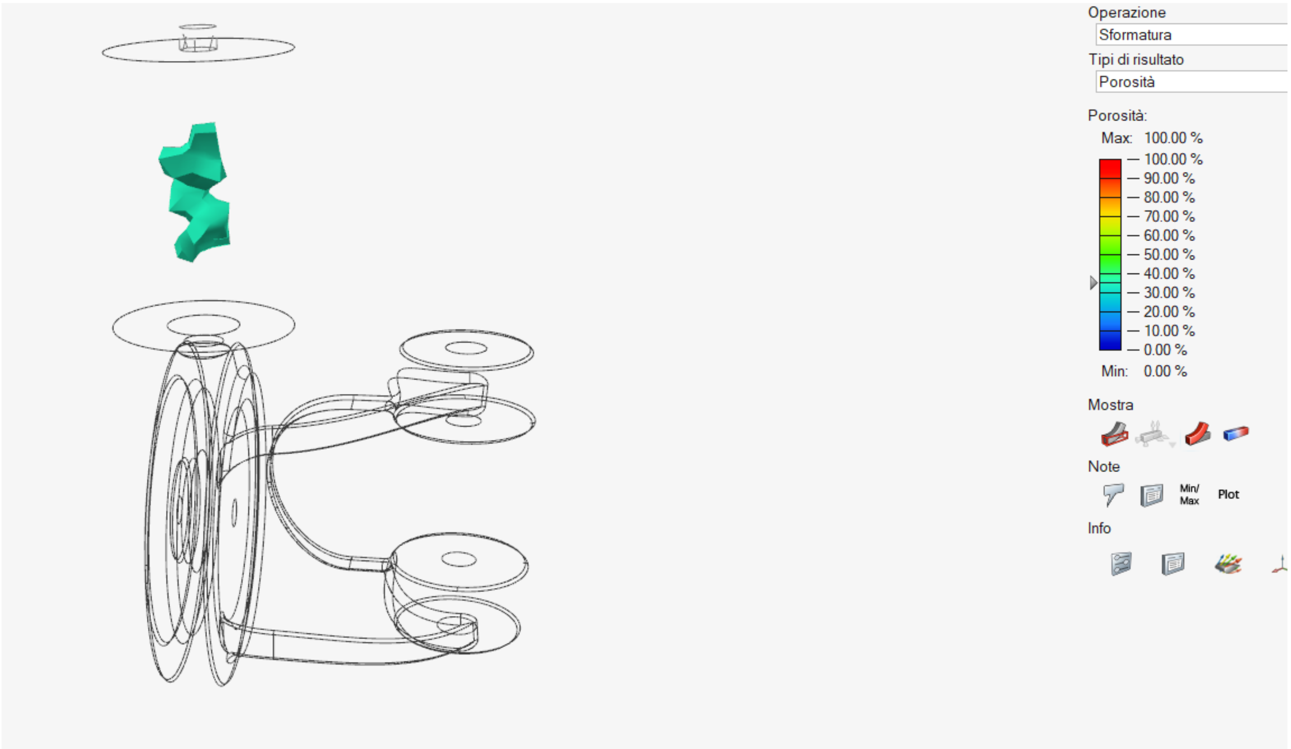
Operazione
Sformatura
Tipi di risultato
Porosità
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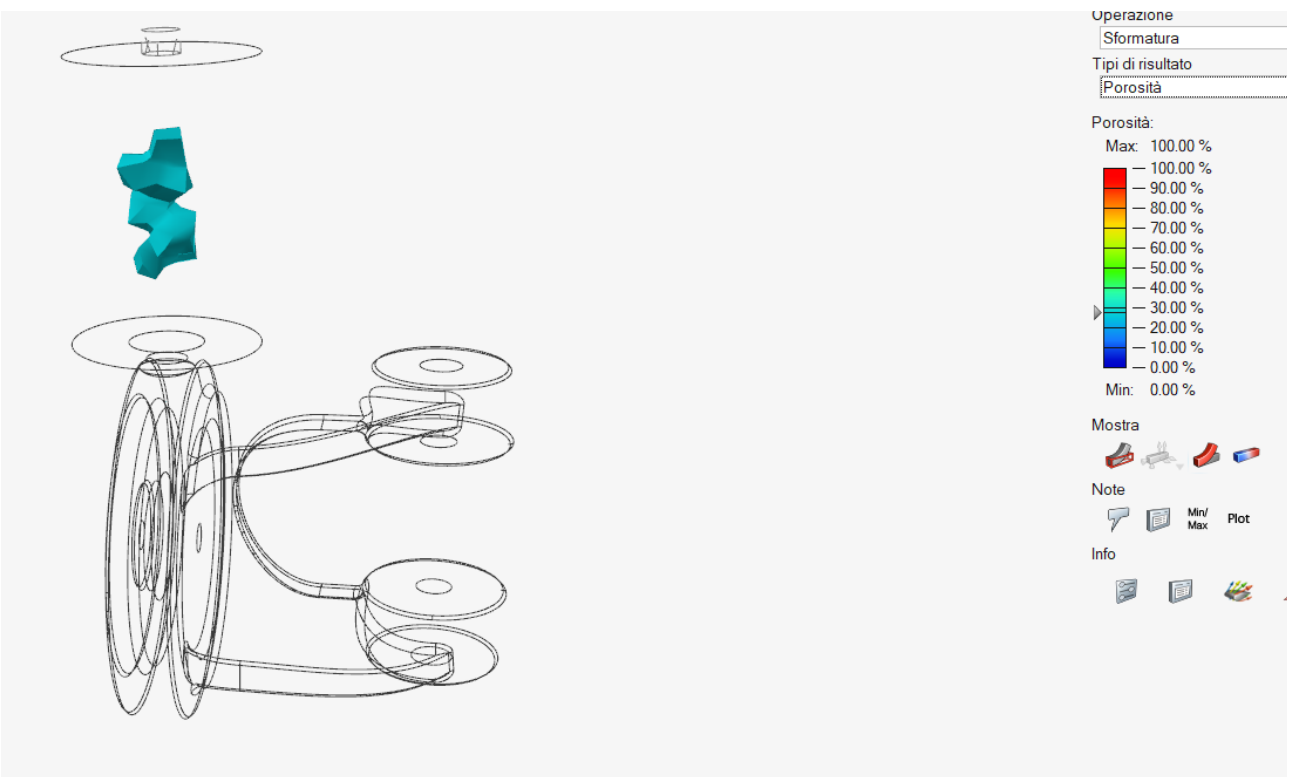
Operazione
Sformatura
Tipi di risultato
Porosità
Porosità:
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100.00 %
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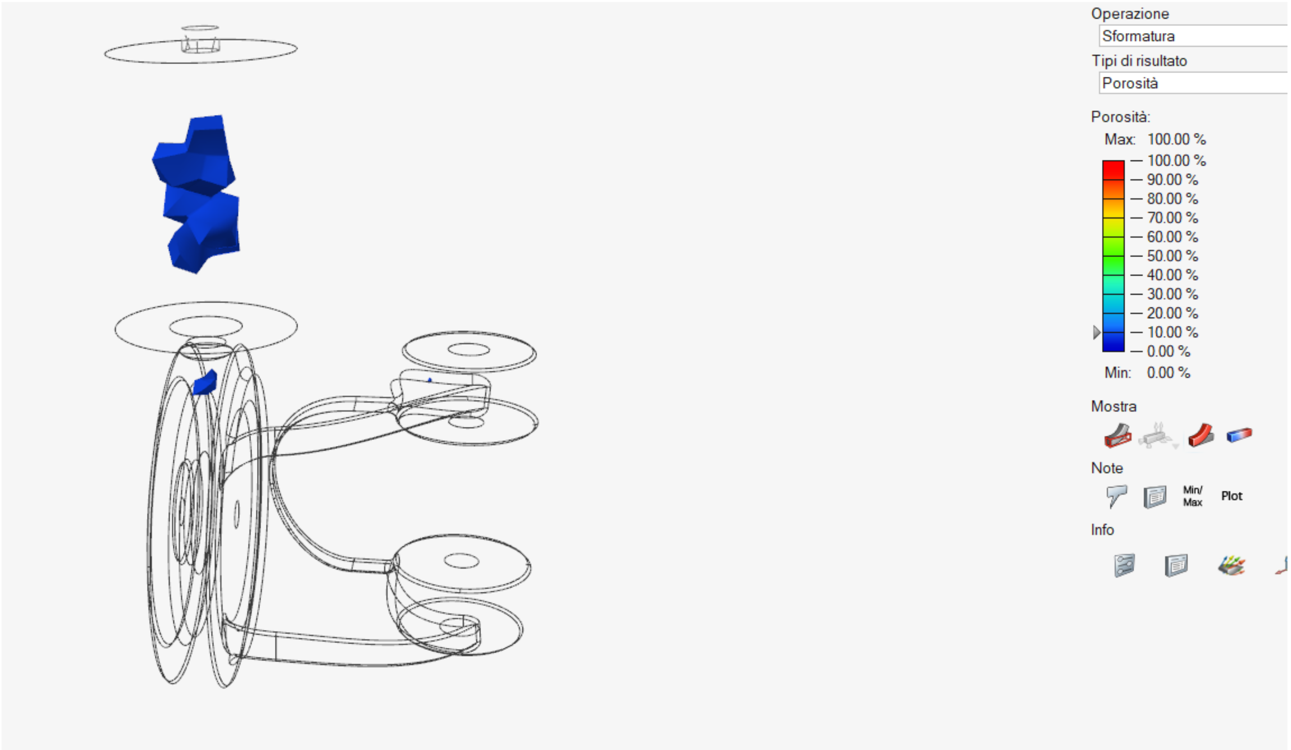
Mostra
Note
Min/ Max
Plot
Info



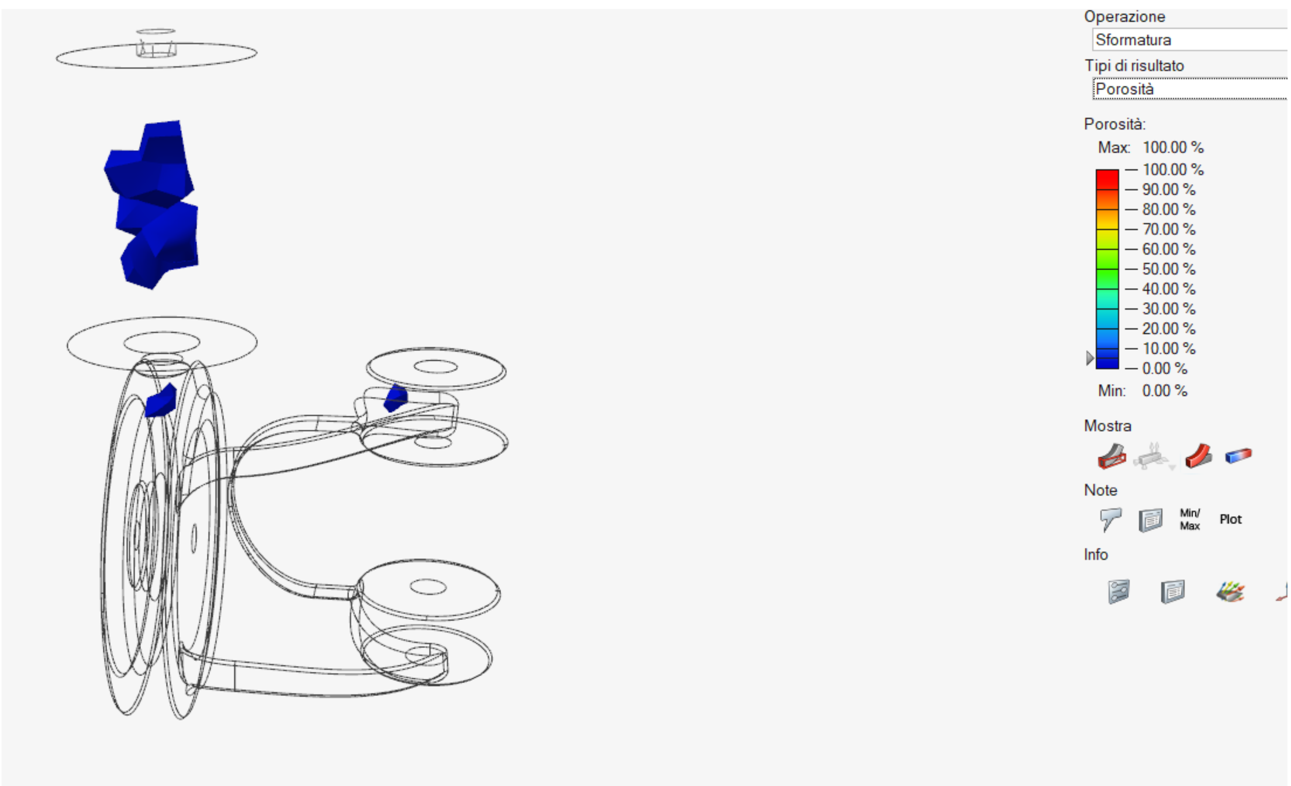


Figure 22: six pictures showing the porosity levels at different percentages

FLASK SELECTION

To select the flasks, we first measured our casting:

- width: b = 145,50 mm
- height: 233 mm
- height from the parting plane to the top of the feeder (pouring point) h_s = 173 mm
- height from the parting plane to the bottom point: h_i =60 mm
- thickness: a = 118,40 mm

At this point, we selected the most suitable pair of flasks, using a table found in the "*UNI 6765-70*".

Serie rettangolare con rapporto b/a = 1,26

a	b	H											
250	315	50	63	80	100	125	160	200					
280	355	50	63	80	100	125	160	200	250				
315	400	50	63	80	100	125	160	200	250	300			
355	450	--	--	80	100	125	160	200	250	300			
400	500	--	--	--	100	125	160	200	250	300	355		
450	560	--	--	--	100	125	160	200	250	300	355		
500	630	--	--	--	100	125	160	200	250	300	355	400	
560	710	--	--	--	100	125	160	200	250	300	355	400	
630	800	--	--	--	100	125	160	200	250	300	355	400	
710	900	--	--	--	--	125	160	200	250	300	355	400	500
800	1000	--	--	--	--	125	160	200	250	300	355	400	500
900	1100	--	--	--	--	--	160	200	250	300	355	400	500
1000	1300	--	--	--	--	--	--	200	250	300	355	400	500
1100	1400	--	--	--	--	--	--	200	250	300	355	400	500
1200	1500	--	--	--	--	--	--	--	250	300	355	400	500
1300	1600	--	--	--	--	--	--	--	250	300	355	400	500
1400	1700	--	--	--	--	--	--	--	--	300	355	400	500
1500	1800	--	--	--	--	--	--	--	--	300	355	400	500

Table 5: table for rectangular flasks, UNI 6765-70

The **flasks** we chose are:

- Lower flask: **250 mm x 315 mm x 63 mm**
- Upper flask: **250 mm x 315 mm x 200 mm**

Since the upper flask is taller by h_s, it will not be filled to the top with sand, but only up to the level defined by h_s.

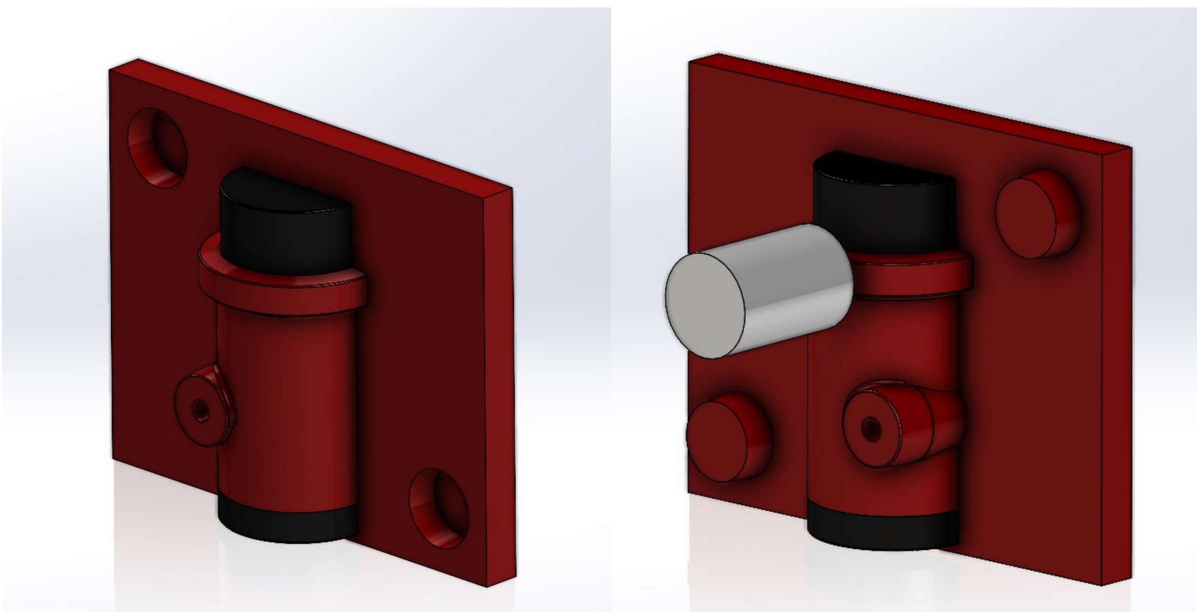
PATTERN PLATES

The pattern plates required to produce our part were designed to be of **birch wood.**

We chose this type of wood because:

- Low cost
- Dimensional stability
- Easily machinable
- Wear-resistant
- Low moisture absorption

The pattern plates are equipped with a system that facilitates their alignment and allows the removal of the feeder from above in fact, the feeder is disconnected from the top pattern plate.



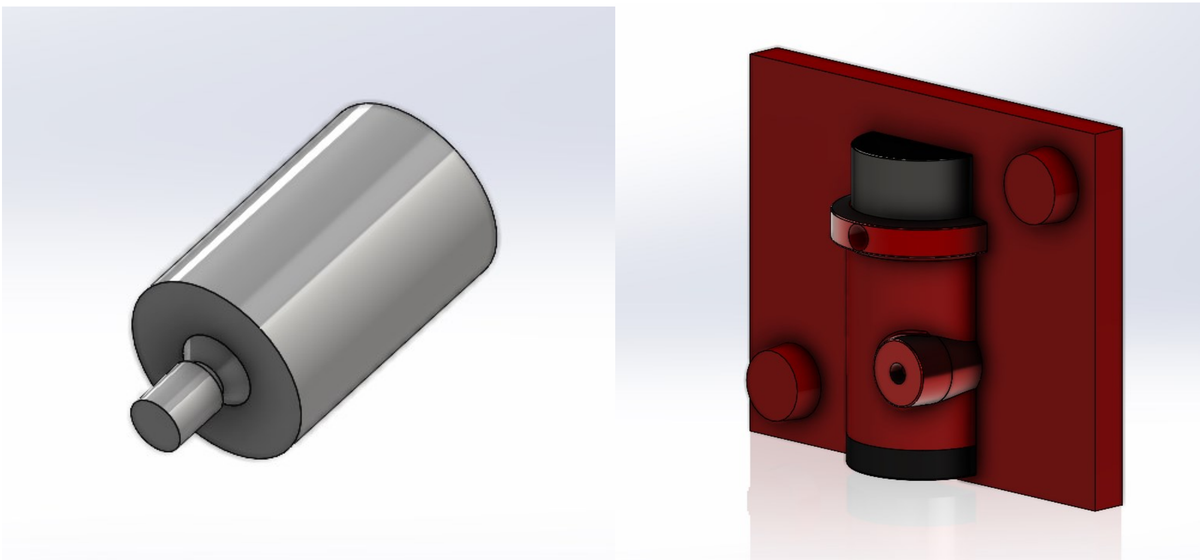


Figure 23: 3D models of the pattern plates and the detachable feeder

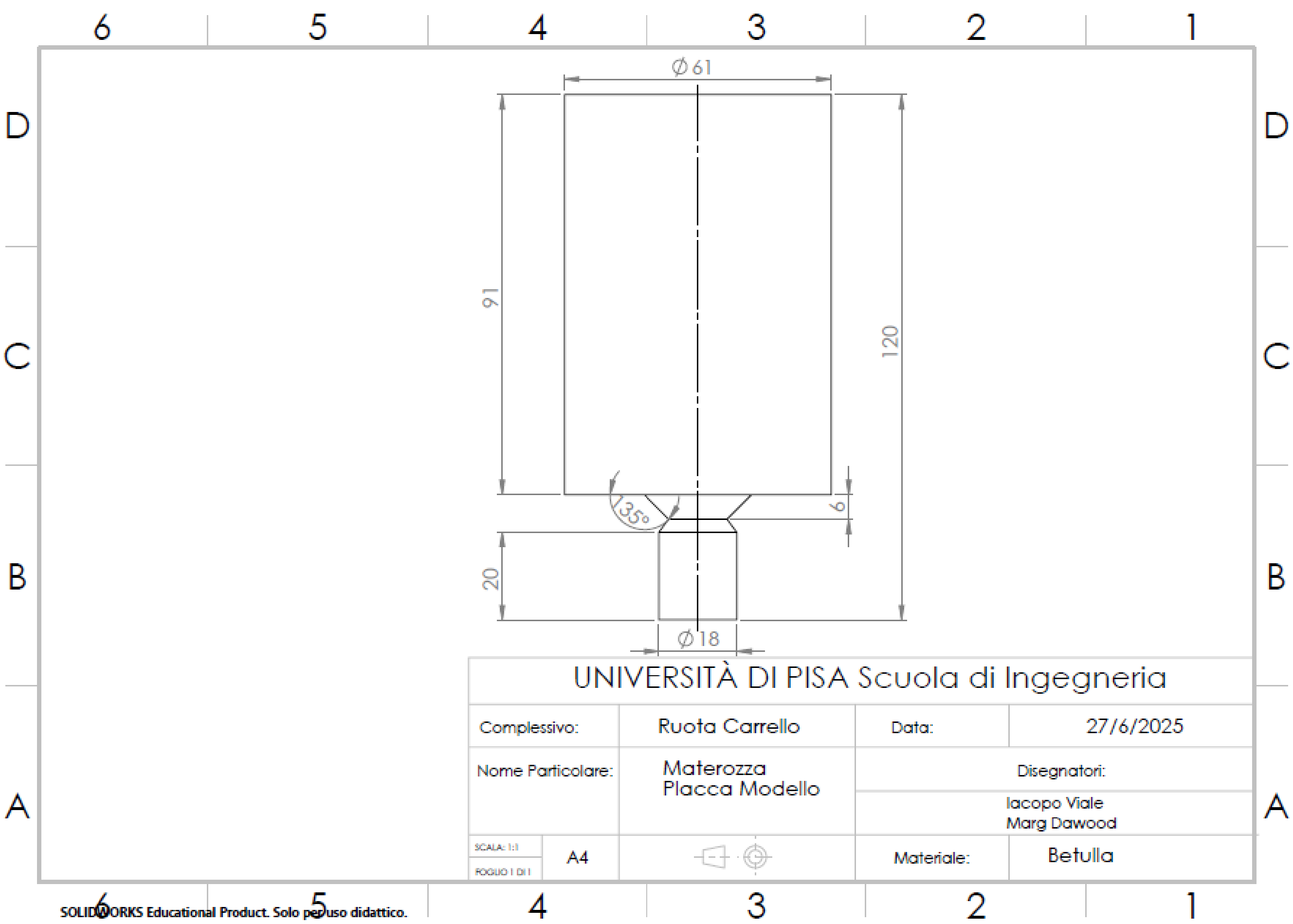


Figure 24: technical drawing “Feeder pattern plate”

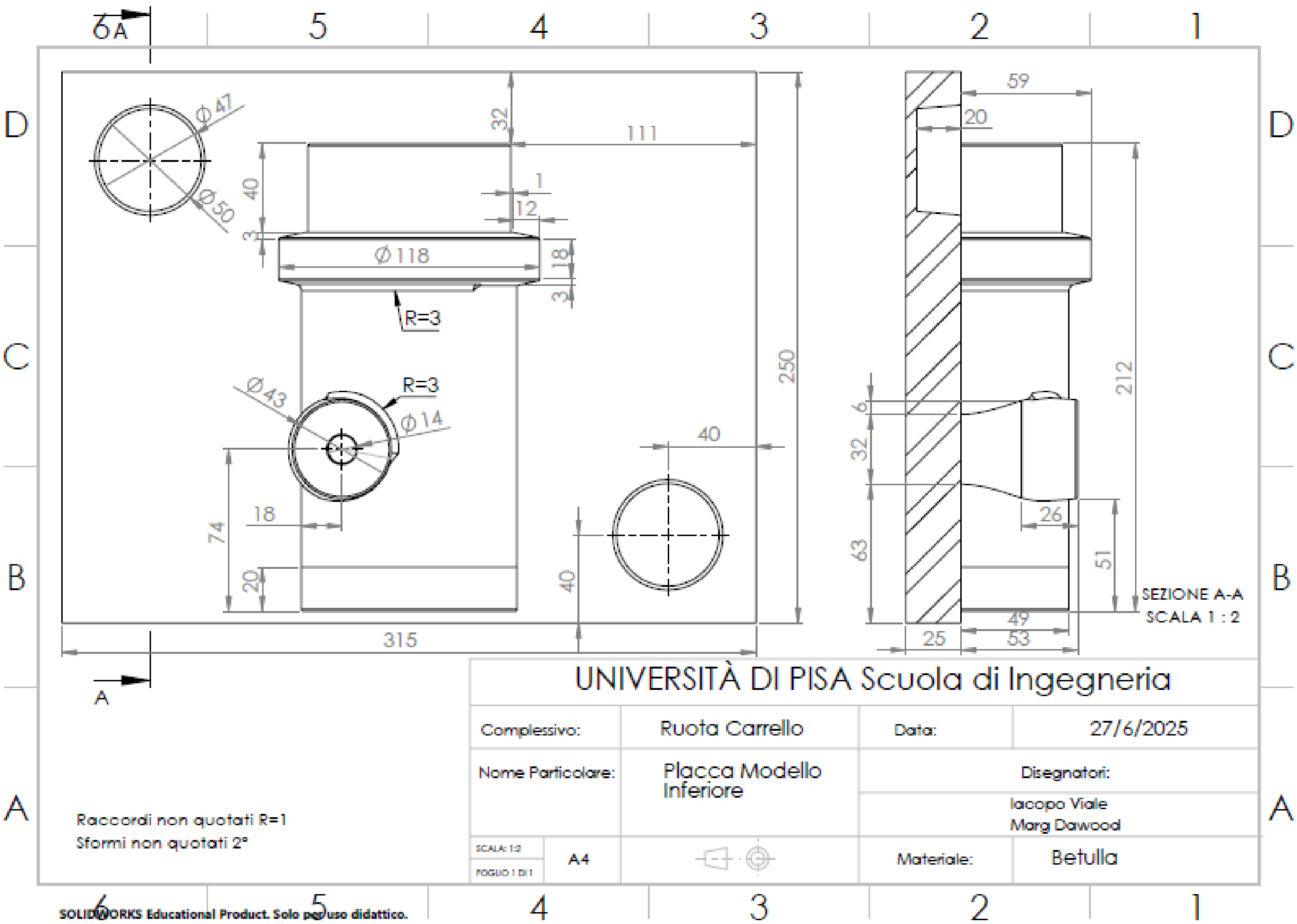


Figure 25: technical drawing “lower pattern plate”

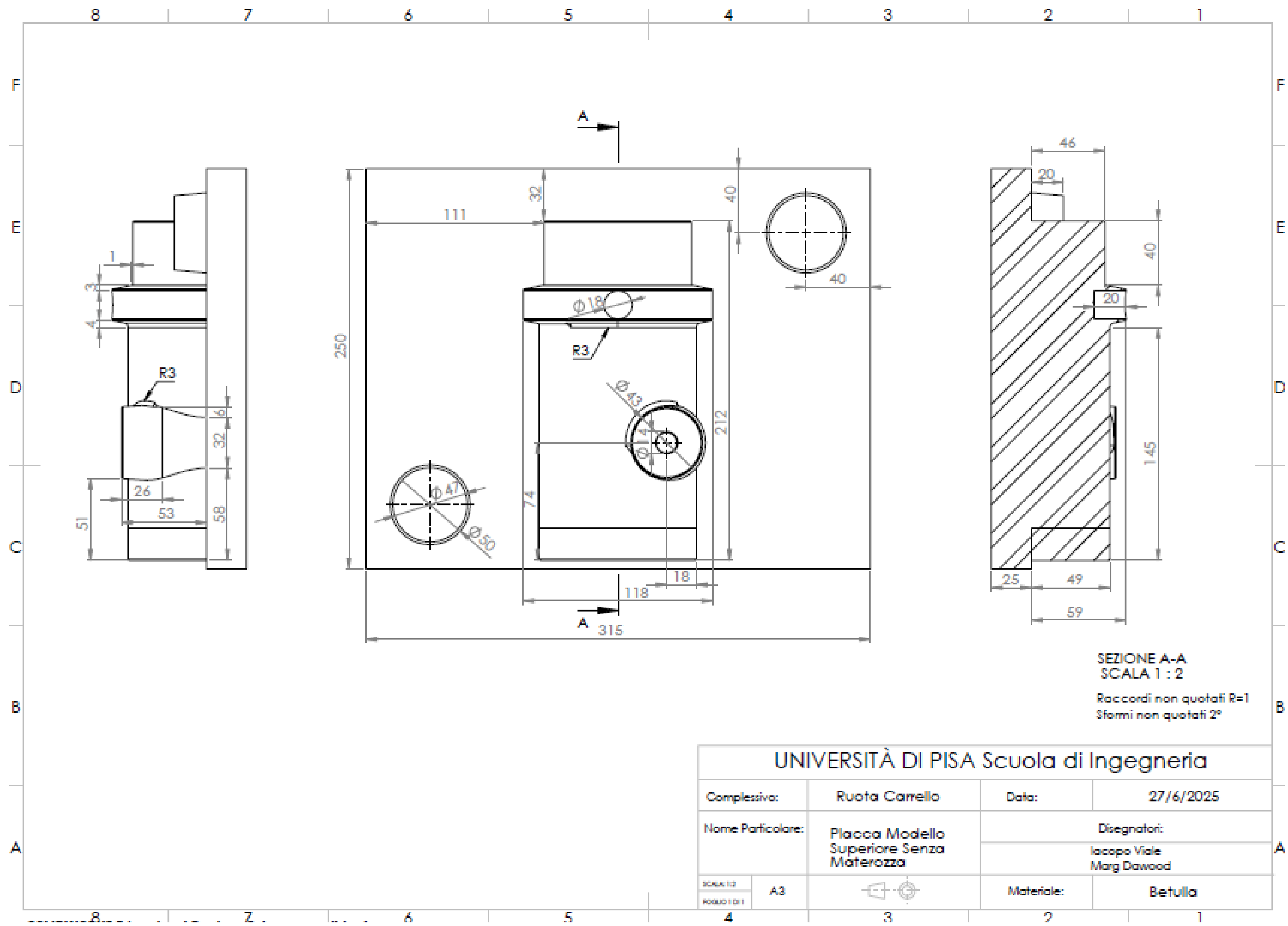


Figure 26: technical drawing “Top pattern plate without feeder”

METALOSTATIC FORCES

Metalostatic forces come from the combination of: pressures on flat surfaces, on cylindrical surfaces and those due to the cores.

To calculate said forces, we must consider the portion of the molten metal (excluding the feeder) present on the top plate.

Below we show this portion and differentiate between flat surfaces, cylindrical surfaces and cores.

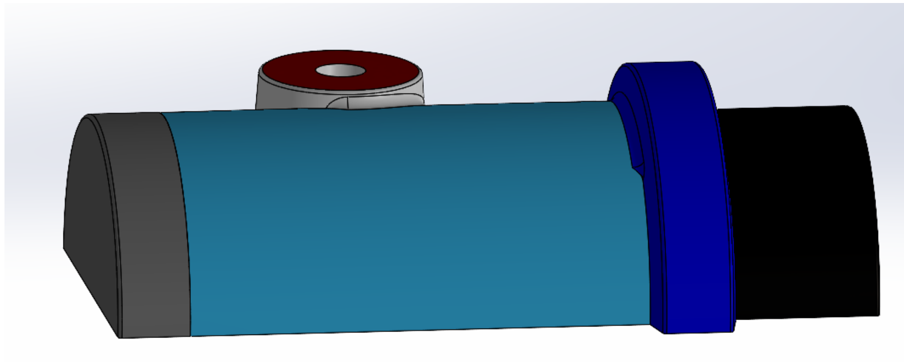


Figure 27: identification and classification of the surfaces used for calculating metalostatic forces

Flat | Cylindrical | Cores

- **Cylindrical surfaces:**
  $F = \delta * D * [H - \pi * (D / 8)] * L$
  D: diameter of cylindrical surface (measured with the software)
  L: length of the surface (measured with the software)
  H = 0,173 m (pouring height measured from the parting plane, measured with the software)
  ρ = 7850 Kg/m^3 (density of steel)
  g = 9,81 m/s^2 (gravitational acceleration)
  $\delta = \rho * g$ = 77008,50 N/m^3 (specific weight of steel)

  - **F1:**
    D = 0,118 m
    L = 0,024 m
    F1 = 27,92 N

  - **F2:**
    D = 0,098 m
    L = 0,098 m
    F2 = 99,49 N

- **Flat surfaces:**
  $F = S * h * \delta$
  h: height of the surface, measured with the software
  S: surface, measured with the software

- **F3:**
  $h = 0{,}067$ m
  $S = 0{,}0013$ m^2
  $F3 = 6{,}71$ N

- **Cores:**
  $F = V * \delta - V_{tot} * \delta_A$
  V: volume submerged in the liquid (measured with the software)
  V_{tot}: total volume of the core (measured with the software)
  $\rho_A = 1590$ Kg/m^3 (sand core density)
  $\delta_A = \rho_A * g = 15597{,}90$ N/m^3

  - **F4:**
    $V = 5{,}77*10^{-5}$ m^3
    $V_{tot} = 0{,}00032$ m^3
    $F4 = -0.58$ N

  - **F5:**
    $V = 7{,}05*10^{-4}$ m^3
    $V_{tot} = 0{,}00107$ m^3
    $F5 = 37{,}65$ N

The total force is given by the sum of the individual forces mentioned above:

$F_{tot} = F1+F2+F3+F4+F5 = 171{,}19$ N

Now we need to verify that the weight of the foundry sand placed above our part is greater than the total force; if that were the case, we would need to add weights on top of the flasks.

The weight of the sand is: $F_s = V_{sand} * \rho_s * g$

$V_{sand} = V_{UpperFlask} – V_{UpperHalfPieceandFeeder}$

$V_{UpperFlask} = (0{,}25m * 0{,}315m * 0{,}173m) = 0{,}0136$ m^3

$V_{UpperHalfPieceandFeeder} = 0{,}00112$ m^3

$\rho_s = 3300$ Kg/m^3

Calculating: $F_s = 404$ N

Since the weight of the sand is greater than the total force we previously calculated, no additional weight needs to be added on top of the flasks during the pouring process.

COST PER PIECE AND CASTING TIMES

Regarding the costs and casting times, we conducted two different studies: the **first** assumes **three workers operating in parallel**, and the **second assumes two workers operating in parallel**.

Another difference is that, in the second case, a single batch of steel is loaded into the furnace.

LABOUR DURING CASTING PHASE

Case 1:

I The times we estimated are:

- Furnace loading: 10 min.
- Melting: 60 min.
- Flask assembly: 2 min.
- Filling sand and cores: 10 min.
- Cooling: 45 min.
- Flask disassembly: 3 min.
- Removal of sand, cores and feeder: 15 min.

The previously estimated pouring time ($T = 3,2 * \sqrt{G} = 7,77$ s) is only a few seconds and was therefore not included. In total, it takes 145 minutes (2,42 h) to complete the first cycle of 3 parts.

In the next cycles, furnace loading and melting begin at the start of the cooling phase of the previous cycle.

In this way, 75 minutes are required for cycles following the first.

Therefore, in a 12-hour workday, it is possible to complete N cycles, where N is:

$N = 1 + \{[(12 * 60) – 145] / 75\} = 8$

Completing 8 cycles means producing 24 parts in one day and, therefore, completing the entire batch in less than 6 days.

The workers are not paid during melting and cooling, as these are passive periods, so for each cycle, they work for a time T given by the sum of the other phases:

T = (10 + 2 + 10 + 3 15) min. = 40 min. = 2/3 h

Hence, considering that a worker costs the company 25€/h and that during that three workers are active during a cycle, producing 24 parts in 8 cycles per day:

$€_{workerperpiece}$ = (2/3 h * 8 * 3 * 25 €/h) / 24 **= 16,70 €**

Case 2:

The thinking process is the same as in "case 1" so we will only be listing the data:

- Furnace loading for the whole day: 30 min.
- Melting for the whole day: 90 min.
- Flask assembly: 2 min.
- Filling sand and cores: 10 min.
- Cooling: 45 min.
- Flask disassembly: 3 min.
- Removal of sand, cores and feeder: 15 min.

As mentioned before, the previously estimated pouring time (T = 3,2 * √G = 7,77 s) was not included. Therefore, it takes a total of 185 minutes (3.08 hours) to produce the 2 parts of the first cycle.

In the subsequent cycles, however, it takes 75 minutes to produce two parts.

N = 1 + {[(12 * 60) – 185] / 75} = 8

This way, we produce 16 pieces a day.

For the cycles following the first, the workers do not work during cooling, melting, and, additionally, they do not need to charge the furnace. So:

T = (2 + 10 + 3 + 15) min. = 30 min. = 0,5 h

This time applies to all 8 cycles, with an additional 0.5h added to the first cycle (the time required to charge the furnace).

$€_{workerperpiece}$ = {[(0,5 h * 8) + 0,5 h] * 2 * 25 €/h} / 16 **= 14,06 €**

SAND

To calculate the cost of foundry sand per part, we need to know: the volume of the flasks, the sand density, the sand cost per Kg and the volume of the pattern plates (excluding alignment pins and the rectangular bases).

- V_{flasks} = [0,25 * 0,315 * (0,173 + 0,063)] m^3 = 0,0186 m^3
- $V_{TopPatternPlate}$ = 0,00112 m^3
- $V_{LowPatternPlate}$ = 0,000852 m^3
- Cost per Kg = 0,25 €/Kg
- ρ_s = 3300 Kg/m^3

Considering that this sand is reusable for up to 15 times, the cost of the sand for one piece is:

$€_{sandperPiece}$ = [(V_{flasks} – $V_{TopPatternPlate}$ – $V_{LowPatternPlate}$) * ρ_s] / 15 **= 0,91 €**

This cost is the same for both studied cases.

METAL

The metal we used, as previously mentioned, has a density of 7850 Kg/m^3 and a price of approximately 0,80 €/Kg (wholesale).

As can be seen in the "*DIN EN ISO 683 – 1*" and "*Steel Recycling Sheet*", it is possible to recycle 80% of the scrap; so, the material used to produce one part is made of: the metal from the finished part plus 20% of the scrap (i.e. the difference between the metal and the finished part).

- $V_{finishedpart}$ = 221625, 42 mm^3
- V_{metal} = 752477,93 mm^3
- $V_{20\%Scraps}$ = (V_{metal} - $V_{finishedpart}$) * 0,20 = 106170,50 mm^3
- ρ_{C45} = 7,85 * 10^{-6} Kg/mm^3

Therefore, the cost of the material that it takes to produce one piece:

$€_{steelperPiece}$ = ($V_{finishedpart}$ + V_{metal}) * ρ_{C45} * 0,80 €/Kg **= 2,06 €**

This cost is the same for both studied cases.

WOODEN MODELS

Birch, the material chosen to produce the wooden models, has a density of ρ_{Birch} = 650 Kg/m^3 and a cost of approximately 3€/Kg.

To make one pattern plate, a worker requires about 4 hours of labor. Since two plates are needed to produce one part, the labor time required per part is 8h.

Knowing that a worker gets paid 25€/h:

$€_{LaborTwoPlates}$ = 25 €/h * 8 h = 200 €

Now we need to calculate the cost of the material.

First of all, it is necessary to size the starting wooden block, and to do so, we need to know:

- plate width: 0,25 m
- plate length: 0,315 m
- maximum height of the piece: 0,233 m
- thickness of the plates: 0,04 m

Knowing that:

$€_{material}$ = [0,25m * 0,315m * (0,233m + 0,04m)] * ρ_{Birch} * 3 €/Kg = 41,93 €

Case 1:

By having three operators working simultaneously, these costs must be multiplied by three.

Amortizing the total over the production batch, the cost for the realization of a single piece amounts to:

€modperPiece = [(200+41,93) * 3] / 140 **= 5,18€**

Case 2:

By having two operators working simultaneously, these costs must be multiplied by two.

Amortizing the total over the production batch, the cost for the realization of a single piece amounts to:

€modperPiece = [(200+41,93) * 2] / 140 **= 3,46€**

ENERGY

According to ISPRA, *"the energy consumption for melting is around 650kWh per tonne of steel"* for an induction foundry furnace.

Knowing that the metal volume is 752477,93 mm^3, that the density of C45 is $7,85*10^{-6}$ Kg/m^3 and that the electricity price is 0,1556 €/kWh:

Case 1:

We load the furnace at each cycle with the amount of metal required for the next cycle and the furnace runs for only one hour.

In each cycle, 3 parts are produced, so the material loaded weighs:

weight = 752477,93 mm^3 * $7,85*10^{-6}$ Kg/m^3 * 3 = 17,72 Kg

By setting up a ratio, we determine the kWh required to melt this amount of steel:

Consumption for melting= (650 kWh * 17,72 Kg) / 1000 Kg = 11,52 kWh

Thus, the energy cost for one part amounts to:

$€_{energyperPiece}$ = (11,52 kWh * 0,1556 €/kWh) / 3 **= 0,60€**

Case 2:

We load the furnace at the beginning of the day with the amount of metal required for the entire daily production, and the furnace remains on all day (12 hours) to keep the steel molten (unlike before).

In one day, 16 parts are produced, so the material loaded weighs:

weight = 752477,93 mm^3 * 7,85*10^{-6} Kg/m^3 * 16 = 94,51 Kg

By setting up a ratio, we determine the kWh required to melt this amount of steel:

Consumption for melting = (650 kWh * 94,51 Kg) / 1000 Kg = 61,43 kWh

As we know from the "*Labor*" paragraph, it takes 1.5 hours to melt. The power of the furnace is: $Pot_{melting}$ = 61,43 kWh / 1,5h = 40,95 kW

During the remaining 10.5 hours, the furnace only needs to keep the steel hot (holding). This phase requires a power (estimated) equal to 10% of the power needed for melting (*ABP Induction: "Energy-saving melting and holding*"):

$Pot_{holding}$ = $Pot_{melting}$ / 10 = 4,10 kWh

$€_{energyperPiece}$ = [(40,95 kW * 1,5 h + 4,10 kWh * 10,5 h) * 0,1556 €/kWh] / 16 **= 1,02 €**

CORES

As seen in the paragraph dedicated to the cores, the material they are made of has a density of 1590 Kg/m^3 and a cost of 0,20 €/Kg.

The total volume of the two cores is:

V_{tot} = (0,000322 + 0,00107) m^3 = 1,39 * 10^{-3} m^3

The cost of a piece is:

$€_{coreperPiece}$ = 1590 Kg/m^3 * 0,20 €/Kg * (1,39 * 10^{-3}) m^3 **= 0,44 €**

This cost is the same for both studied cases.

FLASKS

To produce one part, two flasks are required (one lower and one upper) and, since their estimated cost is €50 each, the total cost is €100.
When working in parallel, we need as many pairs of flasks as there are parts produced simultaneously.

Case 1:

The parts produced simultaneously are three; this means:

$€_{FlasksperPiece}$ = 100 € * 3 / 140 **= 2,14 €**

Case 2:

The parts produced simultaneously are two; this means:

$€_{FlasksperPiece}$ = 100 € * 2 / 140 **= 1,43 €**

FINAL COST

Case 1:

$€_{totperPiece}$ = (16,70 + 0,91 + 2,06 + 5,18 + 0,60 + 0,44 + 2,14) € **= 28,03 €**

Case 2:

$€_{totperPiece}$ = (14,06 + 0,91 + 2,06 + 3,46 + 1,02 + 0,44 + 1,43) € **= 23,38 €**

CASE SELECTION

Despite the number of production days increases, we consider the second case to be the best because, considering the piece we are producing, reducing the final cost by €4,65 brings it closer to market prices.

3D PRINTING

OUR PIECE

The part we decided to produce using 3D printing is the **flange** (part number 4 of the assembly).

Since each wheel requires two flanges, the production **batch consists of 280 units.**

Figure 28: two views 3D model of the "Flange"

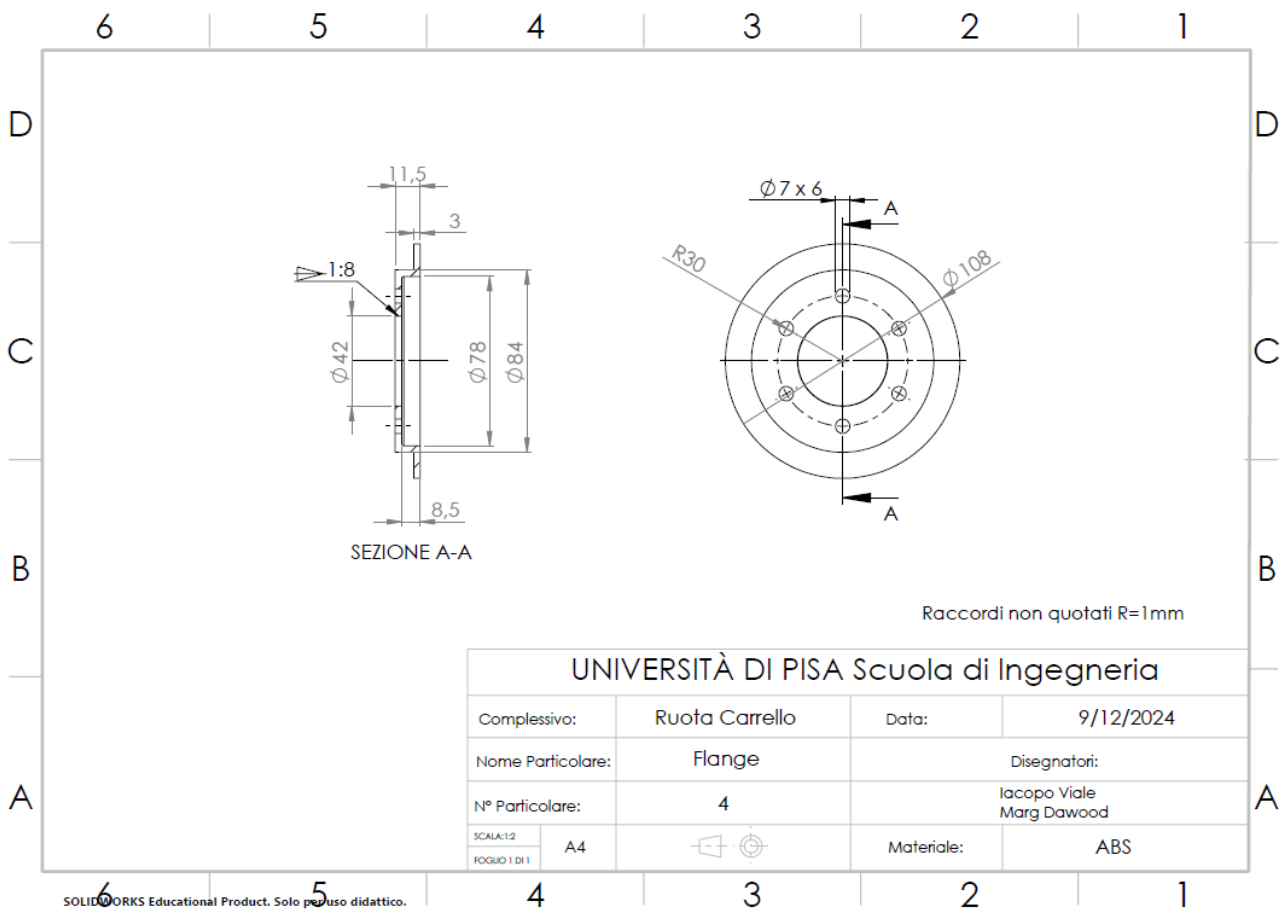


Figure 29: technical drawing of the "Flange"

PRINTING TYPE

The two types of printing we analyzed are **FDM** and MSLA.

Despite the advantages offered by MSLA (for example, better surface finish and the possibility of producing multiple parts in the same time it would take to produce one) we chose to print with filament for the following reasons:

- Our piece does not require a precise surface finish, given its function
- Since it has holes, we avoid the risk of resin being stuck inside them during printing, which could cause the walls of the holes to tilt
- We avoid costs related to personnel safety when working with toxic resins, as well as expenses for post-processing in a UV chamber and for cleaning off the resin. These costs would increase the price too much, considering the type of part we want to produce and its function.

PRINTER

As a printer, we chose to purchase the **Snapmaker J1S**; we also plan to use it in the future for other productions beyond ours, since the manufacturer guarantees 10 years of operation.

Figure 30: printer Snapmaker J1S

MATERIAL

The material choice fell on **ABS** due to its lower cost compared to Nylon, its good mechanical properties (although lower than Nylon) and its ease of use in printing.

The ABS we used will be the one sold on the "*Snapmaker*" website.

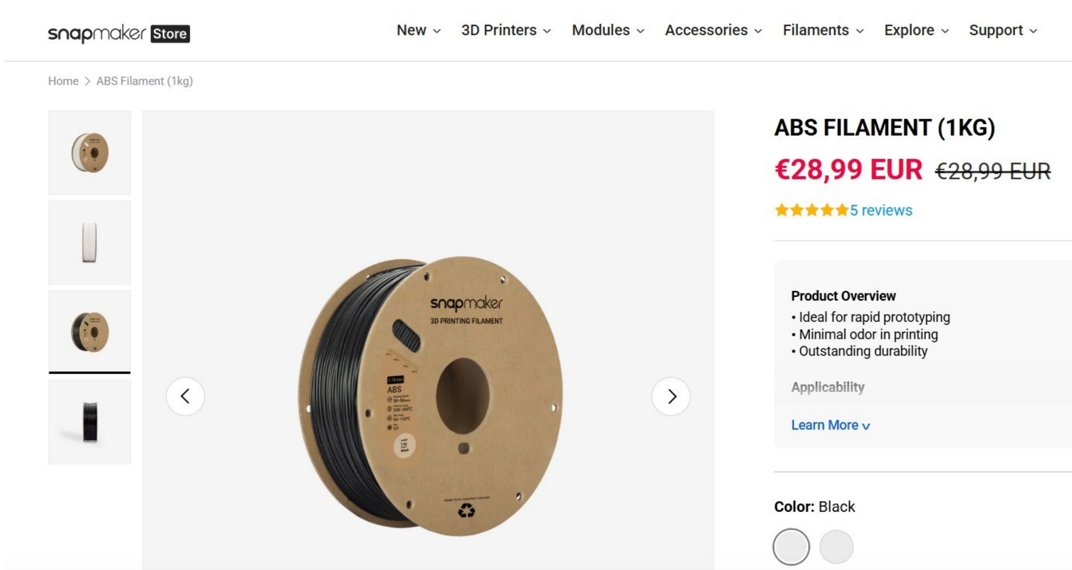


Figure 31: ABS filament snapmaker

SOFTWARE AND PARAMETERS

The software we used to design our printing file is "*Snapmaker Luban*".

Since ABS has a shrinkage of 0.7% along all three axes, we appropriately scaled the part.

Regarding its placement on the print bed, we positioned the part horizontally, with the six holes resting directly on the bed (photo in the 'PRINT SCREEN' section).
The nozzle selected for printing has a diameter of 0.4 mm.

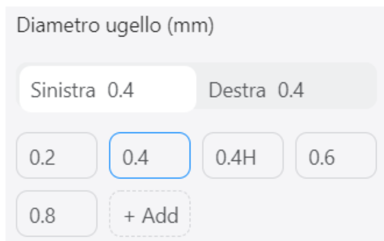


Figure 32: nozzle size selection menu

For the critical angle for support generation, we selected 40°.

The remaining parameters (layer height, speed, infill structure, supports and bed adhesion) were chosen to maximize strength while minimizing print time. The software also helped in this, providing customizable configurations developed based on the desired result.

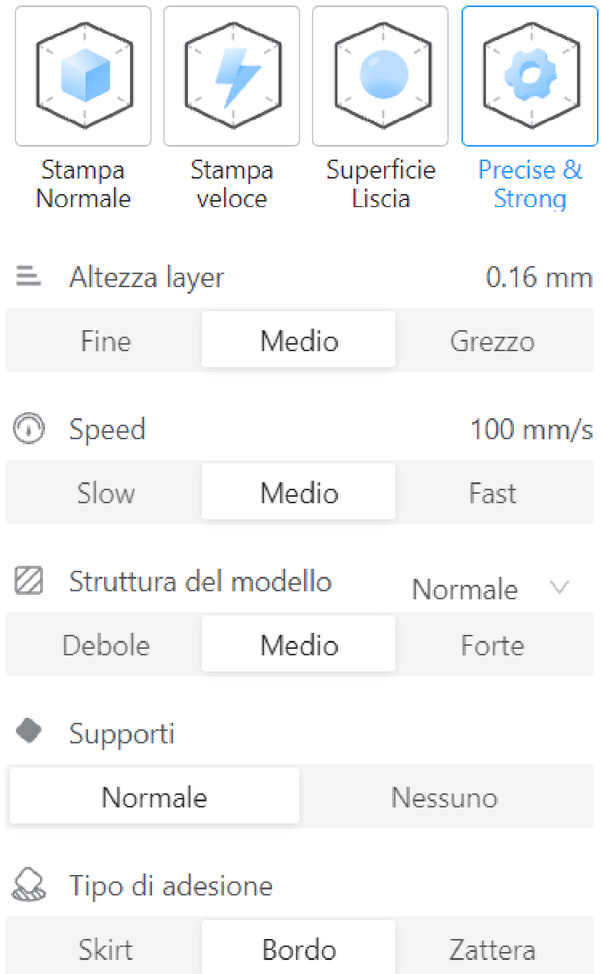
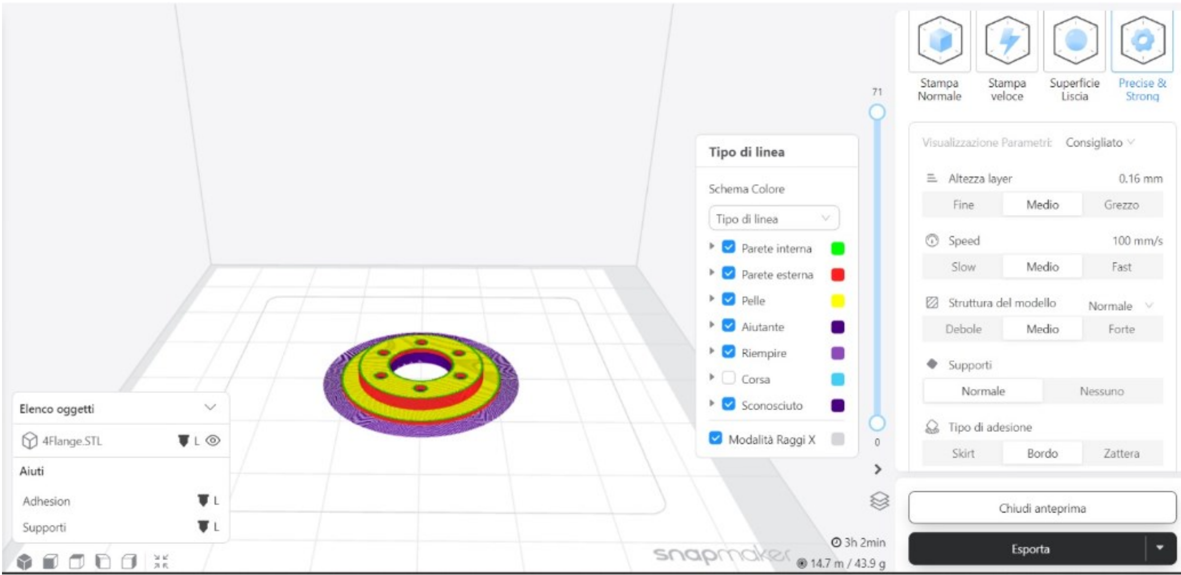
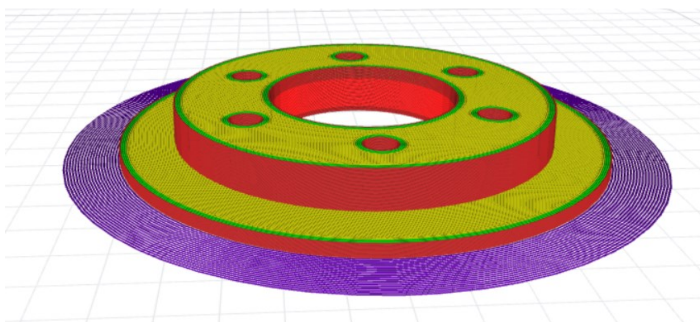
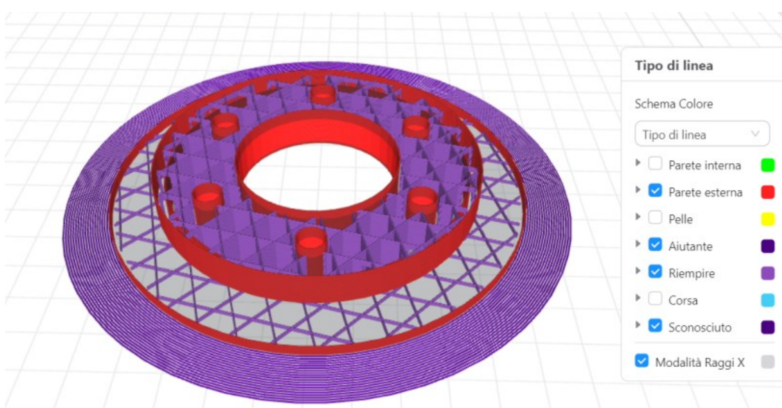


Figure 33: chosen printing parameters

PRINTING SCREENS







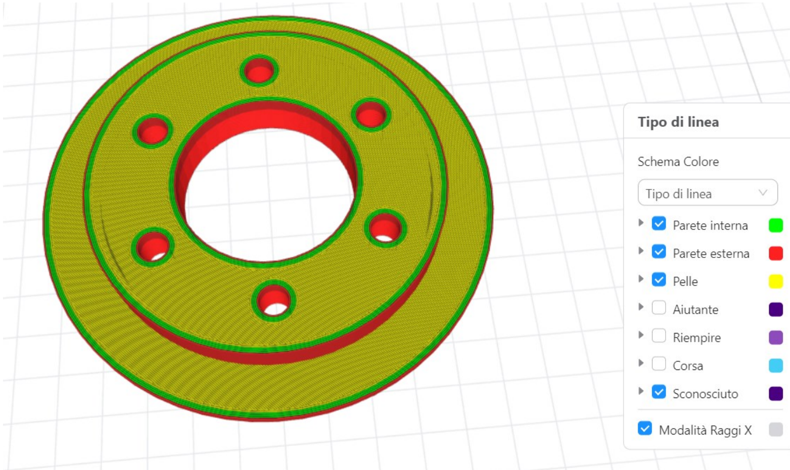


Figure 34: four print pictures of "Flange"

PICTURES OF THE PRINTED PIECE




Figure 35: pictures of the printed piece

PRODUCTION

The print bed can accommodate 9 parts, but since a simultaneous print of 8 parts takes about 24 hours, we decided to reduce daily production to 8 units, allowing us to start printing in the morning and find everything ready the following morning (the printer remains on all day).

By purchasing two printers, daily production would reach 16 parts, enabling us to complete the batch in about 18 days.

COST PER PART

LABOR AND TIME

Considering that the cost of an operator for a company is 25€/h, we estimated the times required for the 3D printing phase.

The times we estimated are:

- Nozzle cleaning: 5 min.
- File loading: 1 min.
- Bed leveling: 2 min.
- Preheating: 2 min.
- Object removal: 2 min.
- Object cleaning (burrs and supports): 10min.

However, an operator works on 8 parts per cycle, so the times for "*object removal*" and "*object cleaning*" must be multiplied by eight, resulting in a total working time per cycle equal to:

T = [5 + 1 + 2 + 2 + (2 + 10) * 8] min. = 106 min. = 1,77 h

Knowing that we can estimate the labor cost per piece:

$€_{\mathbf{laborperPiece}}$ = (25 €/h * 1,77 h) / 8 **= 5,53 €**

MATERIAL

As seen previously, 1 Kg of ABS costs 28,99 €, and to produce one part (as indicated by the software), we need 43,9 g.

Approximately 10% of material is lost during cleaning (and other steps), bringing the total amount of ABS required to produce one part to 48.29 g.

The cost of the material to produce one piece is:

$€_{\mathbf{materialperPiece}}$ = (28,99 € * 48,29 g) / 1000 g **= 1,40 €**

MACHINE

The Snapmaker J1S, as mentioned earlier, costs 1177,97 € and comes with a guaranteed lifespan of 10 years. For this reason, we assume that the company will keep the two printers for at least this period of time, allowing the cost of these machines to be amortized not only over the batch of 280 flanges but also across future productions

The hourly cost of the machine is:

$€_{macchinel'ora}$ = (2 * 1177,97 €) / (10 * 365 * 24) = 0,027 €/h

By using the machines in parallel, in 24,24 hours (one cycle) we produce 16 parts, therefore:

$€_{\mathbf{machineperPiece}}$ = (0,027 €/h * 24,24 h) / 16 **= 0,041 €**

ENERGY

To calculate the energy cost, we need to know the power consumption during the heating and printing phases:

During the 2 minutes (0.033 hour) heating phase, the machine consumes 350W

During the printing phase (24,24 h), the power is 150 W

Assuming a fixed electricity cost during the day of 0,1556 €/kWh.

The energy cost per part is:

$\text{€}_{energyperPiece}$ = [(0,35 kW * 0,033 h + 0,15 kW * 24,24 h) * 0,1556 €/kWh] / 8 = **0,071 €**

TOTAL COST

Adding up all these costs, we get the total price:
$\text{€}_{totperPiece}$ = (5,53 + 1,40 + 0,041 + 0,071) € **= 7,042 €**

Since each wheel has two flanges, their cost in the final price of the wheel is approximately 14,08 €.

MACHINING

MATERIAL

For the chip removal process, we decided to analyze **part 7**, namely the **Shaft**.

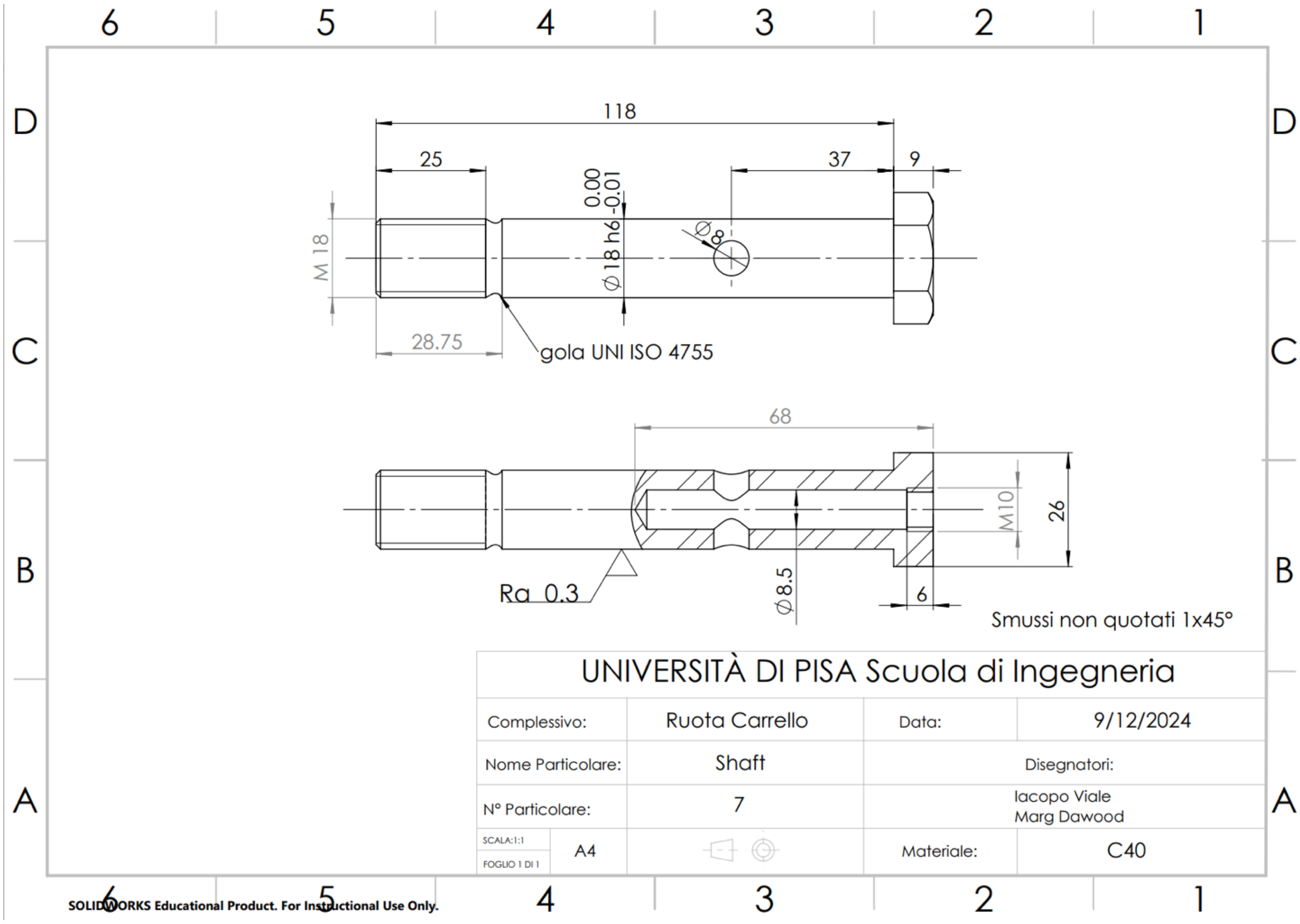


Figure 36: technical drawing of the "Shaft"

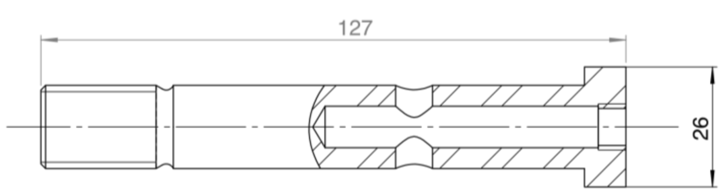


Figure 37: overall dimensions of the "Shaft"

We chose **C40 steel** as the material, since this type of steel offers **good mechanical strength**, is **easily machinable** with machine tools, and is suitable for withstanding the loads and stresses typical of a wheel shaft for trolleys.

Its composition, with about 0.4% carbon, ensures high hardness and tensile strength without causing excessive difficulties during cutting operations. It is also a very economical steel since it does not contain high percentages of valuable alloying elements such as nickel or chromium, making its production process less expensive compared to alloyed or stainless steels.

Our starting stock is a **cylindrical semi-finished** piece with initial dimensions D=30mm and L=130mm.

The required production **batch** is **140 parts**.

COMPOSIZIONE CHIMICA	C%	Si% (max)	Mn%	P% (max)	S% (max)	Cr% (max)	Mo% (max)	Ni% (max)
	0,37 - 0,44	0,40	0,50 - 0,80	0,030	0,035	0,40	0,10	0,40

PROPRIETA' MECCANICHE	Stato	Sezione (mm)	Rm (MPa)	Re (MPa) min	A% min	KV(J) min (20°C)	HB	Note
	laminato	d≤16	580	320	16			normalizzato
		16<d≤100	550	290	17			
		100<d≤250	530	260	17			
		d≤16	650 - 800	460	16	30	200 - 240	bonificato
		16<d≤40	630 - 780	400	18		192 - 232	
		40<d≤100	600 - 750	350	19		178 - 225	
	trafilato	5<d≤10	700 - 1000	540	6			
		10<d≤16	650 - 980	460	7			
		16<d≤40	620 - 920	365	8			
		40<d≤63	590 - 840	330	9			
		63<d≤100	550 - 820	290	9			

Table 6: mechanical properties of C40 steel

SURFACES

We started by numbering all the surfaces that require machining, and then we analyzed the most critical ones:

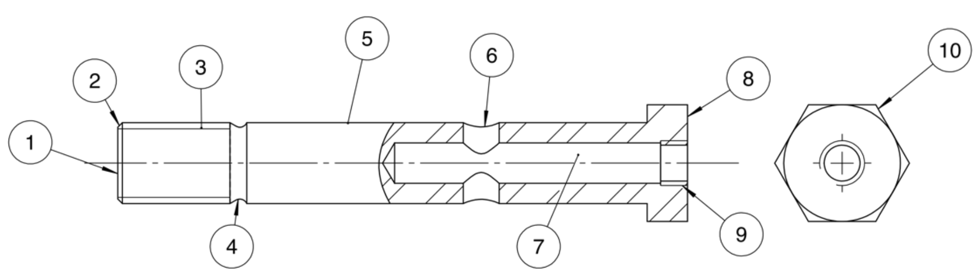


Figure 38: numbered surfaces of the "Shaft"

We have a total of **10 surfaces** to machine.

For holes 6 and 7, we could have used either turning or drilling, but we opted to turn hole 7 (since it is coaxial) and, for greater precision, we chose to drill hole 6. Neither requires boring, as both are clearance holes without tight tolerances.

Regarding the tapping of surface 9, we decided to use a manual tap since our daily production batch is small and the hole is an M10, which makes it difficult to machine on a lathe.
For surface 5, a grinding operation will be performed, as it has precision fits with the frame and the bush.

N° Surf.	Surface type	Possible processes
4,5	External coaxial cylinders	Turning
1,8	Planes orthogonal to axis of 4	Turning/Milling
3	External threading	Turning
7	Internal cylinder coaxial to 4	Turning/Drilling
9	Internal threading	Manual/machine tapping
6	Internal cylinder	Drilling
10	Flat	Milling
2	External chamfer	Turning
5	External cylinder	Grinding

Table 7: list of possible processes

Based on the considerations made, we selected the following machining operations:

N° Surf.	Processes
5,4,2,1,8,3	Turning
7,6	Drilling
10	Milling
5	Grinding
9	Tapping

Table 8: chosen machining processes for our surfaces

We defined the sequence of operations prioritizing **economic and operational logic**: minimizing workpiece repositioning and grouping similar operations together.

The sequence in which we decided to perform the machining operations is as follows:

1. Facing surf 1

2. Roughing surf 5
3. Chamfer surf 2
4. Finishing surf 5
5. External groove surf 4
6. External threading surf 3
7. Facing surf 8
8. Drilling surf 7
9. Tapping surf 9
10. Drilling surf 6
11. Milling esagonale surf 10
12. Grinding surf 5

MACHINES

LATHE

PARALLEL LATHE “GRAZIOLI” DANIA 25

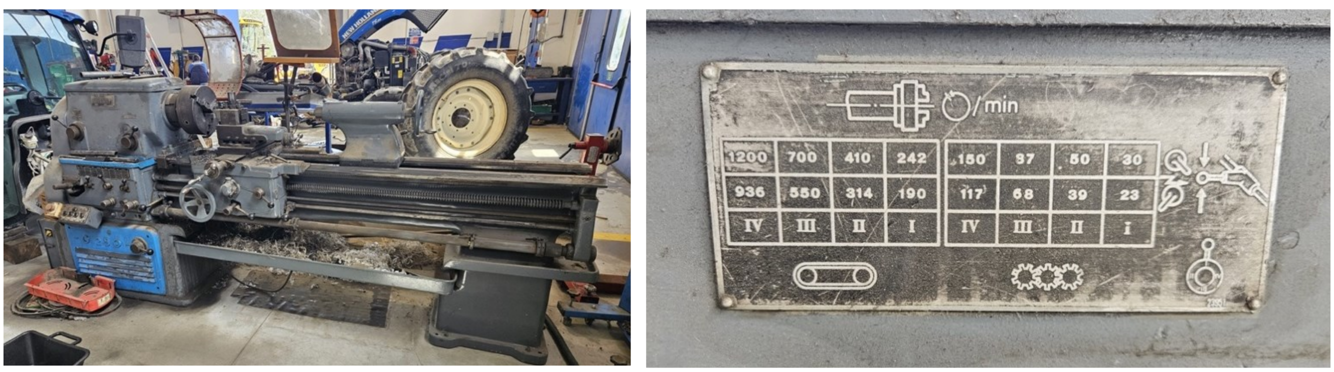


Figure 39: on the left, the photo of the lathe; on the right, the plate with spindle indexing intervals

Maximum turning diameter	[mm]	500
Spindle bore	[mm]	78
Number of spindle speeds	[N]	24
Spindle revolutions per minute	[rpm]	12÷1400
Three-phase asynchronous motor for the spindle	[HP]	10
Cross slide travel	[mm]	250
Tool post travel	[mm]	140
Longitudinal and transverse feeds	[N°]	72
Range of longitudinal feeds	[mm/rev]	0.05÷1.17
Range of transverse feeds	[mm/rev]	0.026÷0.585
Centrifugal electric pump	[HP]	0.2

Table 9: specifications of the parallel Lathe "GRAZIOLI" Dania 25

MILLING MACHINE

LAGUN MILLING MACHINE

Figure 40: Lagun milling machine

Table dimensions	[mm]	1372 x 280
T-slots	[N°]	3
Spindle speed	[rpm]	60÷4200
Saddle travel	[mm]	570
X-axis travel	[mm]	800
Y-axis travel	[mm]	345
Z-axis travel	[mm]	400
Head tilt left-right	[degrees]	90
Head tilt forward-backward	[degrees]	45
Quill travel	[mm]	127
Quill diameter	[mm]	85.7
Main motor	[HP]	4

Table 10: specifications of Lagun milling machine

DRILL

COLUMN DRILL AUDAX MODEL 50 TI

Figure 41: Column drill a AUDAX model 50 TI

Figure 42: plates with spindle indexing and feed increments

Table dimensions	[mm]	550
Morse taper	[N°]	4
Number of spindle speeds	[N]	12
Spindle revolutions per minute	[rpm]	55÷600
Quill travel	[mm]	210
Maximum diameter	[mm]	50
Power	[HP]	3
Motor power	[Kw]	2.2

Table 11: specifications of Column drill a AUDAX model 50 TI

GRINDER

CYLINDER GRINDER VOUMARD 5A


Figure 43: cylinder grinder Voumard 5A

Power	[kW]	7.5
Capacity	[mm]	ø5÷200x250
Maximum distance from work head to wheel	[mm]	550
Center height	[mm]	180
Maximum grinding depth	[mm]	250
Maximum grinding diameter	[mm]	5÷200
Wheel speed	[Rpm]	3600÷40000
Cross-feed speed	[mm/min]	0÷10.000
Rotational speed	[Rpm]	125÷1000

Table 12: specifications of the cylinder grinder Voumard 5A

EQUIPMENT

T-HANDLE TAP WRENCH

The T-handle tap wrench is a tool used for manual tapping.

It is usually equipped with two handles that allow hand rotation. The tapping is performed progressively, starting at the end according to the diameter of the thread and then finishing with the diameter at the thread's crest.

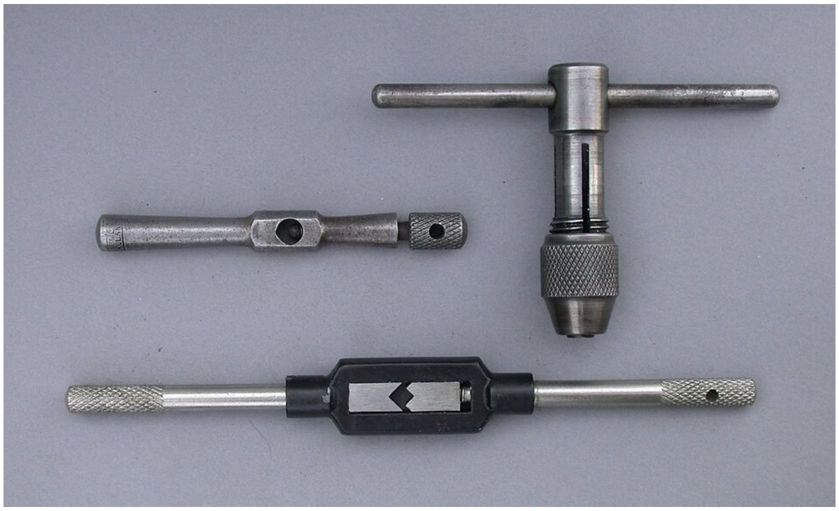
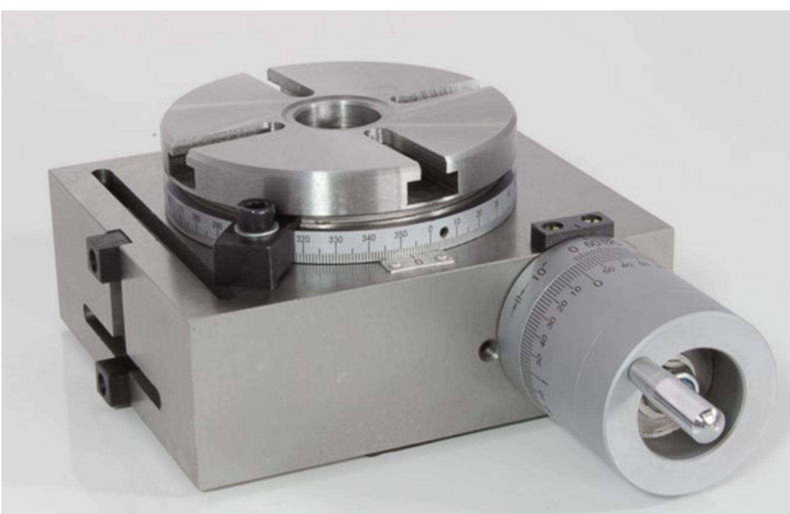


Figure 44: three types of T-handle tap wrench

DIVIDER

To create the hexagonal head, we decided to use a rotary table or divider, which allows precise rotations of the workpiece.



Caratteristiche ≡

Lunghezza	100 mm
Larghezza	8 mm
Altezza	74 mm
Peso	12 kg
Materiale	PER
Forma	Rotondo
Numero articoli per confezione	1 numero di articoli
Garanzia	1 aa
Certificazione NF	NF126
Referenza ManoMano	ME9102806
MMID	564408451226
Rif. costruttore	TVD-100

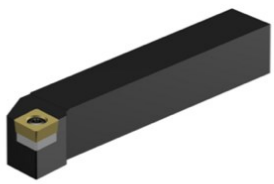
Figure 45: on the right the divider and on the left the specifications

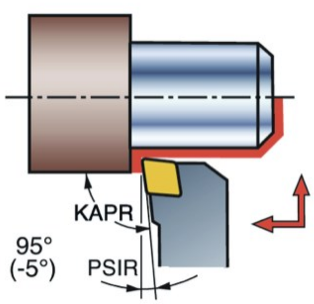
TOOLS

TURNING

Facing roughing e chamfer.

TOOL: SCLCR 2020K 12

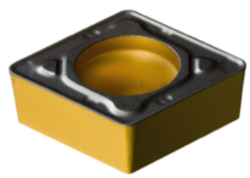


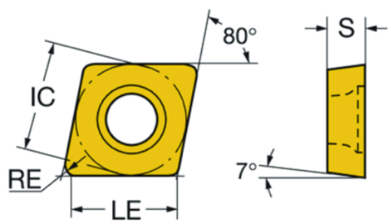


Angolo del tagliente dell'utensile (KAPR_1)	**95 °**
Angolo di attacco dell'utensile (PSIR)	**-5 °**
Codice del tipo di bloccaggio (MTP) ⓘ	**clamp with screw through hole**
Parte 2 identificativi interfaccia articoli da taglio (CUTINT_MASTER)	**CCMT 120408**
Interfaccia adattatore lato macchina (ADINTMS)	**Rectangular shank -metric: 20 x 20**
Angolo massimo lavorazione del piano inclinato (RMPX)	**0 °**
Angolo del corpo lato pezzo (BAWS)	**0 °**
Angolo del corpo lato macchina (BAMS)	**0 °**
Sporgenza massima (OHX)	**21,7 mm**
Versione (HAND)	Right

Figure 46: tool SCLCR 2020K 12 and its specifications from the catalog "Sandvik"

INSERT: CCMT 12 04





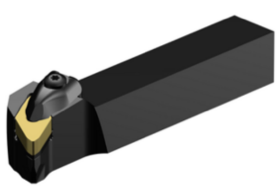
Specifiche dei prodotti — Metrica / Imperiale

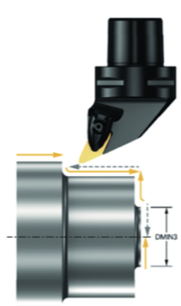
Livello 1 di classificazione del materiale (TMC1ISO)	P M
Geometria (CBMD)	**PR**
Tipo di operazione (CTPT)	**roughing**
Codice del tipo di montaggio dell'inserto (IFS)	**Partly cylindrical, 40-60 deg countersink on one or two sides**
Diametro del foro di fissaggio (D1)	**5,5 mm**
Misura e forma dell'inserto (CUTINT_SIZESHAPE)	**CC1204**
Numero di taglienti (CEDC)	**2**
Diametro del cerchio inscritto (IC)	**12,7 mm**
Codice della forma dell'inserto (SC)	**Rhombic 80**
Lunghezza effettiva del tagliente (LE)	**11,6959 mm**
Raggio di punta (RE)	**1,1906 mm**

Figure 47: insert CCMT 12 04 and its specifications from the catalog "Sandvik"

FINISHING

TOOL: CP-25BR-2020-12



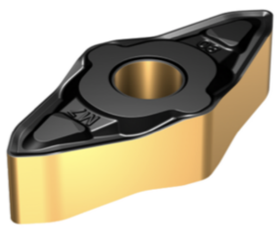


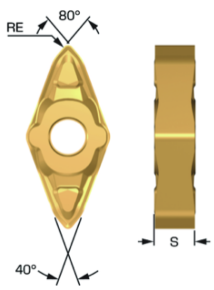
Specifiche dei prodotti — Metrica / Imperiale

Angolo del tagliente dell'utensile (KAPR_1)	**95 °**
Angolo del tagliente dell'utensile (KAPR_2) ⓘ	**25 °**
Angolo di attacco dell'utensile (PSIR)	**-5 °**
Codice del tipo di bloccaggio (MTP)	**clamp on top of insert and into hole**
Parte 2 identificativi interfaccia articoli da taglio (CUTINT_MASTER)	**CoroTurn PRIME CP-B (CP-B1208D)**
Interfaccia adattatore lato macchina (ADINTMS)	**Rectangular shank -metric: 20 x 20**
Angolo massimo lavorazione del piano inclinato (RMPX)	**23 °**
Angolo del corpo lato pezzo (BAWS)	**0 °**
Angolo del corpo lato macchina (BAMS)	**0 °**

Figure 48: tool CP-25BR-2020-12 and its specifications from the catalog "Sandvik"

INSERT: CP-B1208D-M7 4415





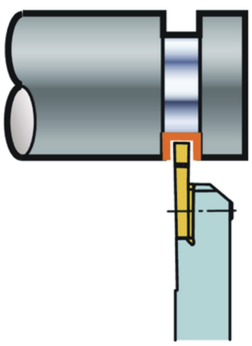
Specifiche dei prodotti ◉ Metrica ○ Imperiale

Livello 1 di classificazione del materiale (TMC1ISO)	P K
Geometria (CBMD)	**M7**
Tipo di operazione (CTPT)	**pre-machining with demand on surface**
Codice del tipo di montaggio dell'inserto (IFS)	**Cylindrical fixing hole**
Diametro del foro di fissaggio (D1)	**5,156 mm**
Misura e forma dell'inserto (CUTINT_SIZESHAPE)	**CoroTurn PRIME CP-B12D**
Numero di taglienti (CEDC)	**4**
Diametro del cerchio inscritto (IC)	**12 mm**
Raggio di punta (RE)	**0,8 mm**
Ampiezza della superficie (BN)	**0,2 mm**
Angolo della superficie (GB)	**0 °**
Angolo di spoglia superiore dell'inserto (GAN)	**18 °**

Figure 49: insert CP-B1208D-M7 4415 and its specifications from the catalog "Sandvik"

GROOVE

TOOL: SMALL 08C3



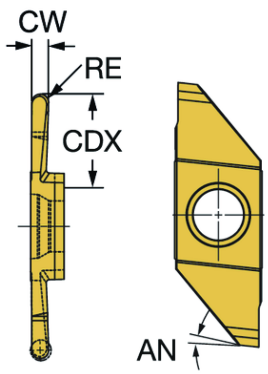
Specifiche dei prodotti — Metrica / Imperiale

Profondità di taglio massima (CDX)	**8,5 mm**
Codice del tipo di bloccaggio (MTP)	**clamp with screw through hole**
Parte 2 identificativi interfaccia articoli da taglio (CUTINT_MASTER)	**CoroCut XS -size 3L (MACL 3 200-N)**
Sede inserto (SSC_M)	**3**
Interfaccia adattatore lato macchina (ADINTMS)	**Rectangular shank -inch: 1/2 x 1/2**
Angolo del corpo lato pezzo (BAWS)	**0 °**
Sporgenza massima (OHX)	**27 mm**
Versione (HAND)	**Left**
Codice tipo ingresso refrigerante (CNSC)	**without coolant entry**
Codice tipo di uscita refrigerante (CXSC)	**no coolant exit**

Ulteriori dati sui prodotti

Figure 50: tool SMALL 08C3 and its specifications from the catalog "Sandvik"

INSERT: MAPL 3 080 1025



Specifiche dei prodotti

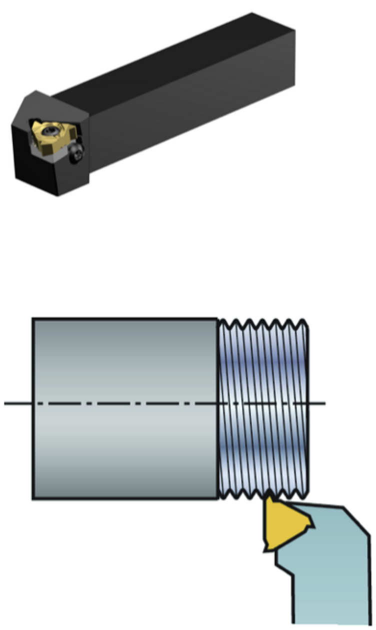
Metrica Imperiale

Livello 1 di classificazione del materiale (TMC1ISO)	P M K N S
Geometria (CBMD)	**MAP**
Tipo di operazione (CTPT)	**finishing**
Codice del tipo di montaggio dell'inserto (IFS)	**Partly cylindrical, 40-60 deg countersink on one or two sides**
Misura e forma dell'inserto (CUTINT_SIZESHAPE)	**CoroCut XS -size 3L**
Numero di taglienti (CEDC)	**2**
Sede inserto (SSC_M)	**3**
Larghezza di taglio (CW)	**0,8 mm**
Tolleranza inferiore larghezza di taglio (CWTOLL)	**-0,025 mm**
Tolleranza superiore larghezza di taglio (CWTOLU)	**0,025 mm**
Raggio di punta (RE)	**0,4 mm**
Tolleranza inferiore raggio di punta (RETOLL)	**-0,025 mm**

Figure 51: insert MAPL 3 080 1025 and its specifications from the catalog "Sandvik"

THREADING

TOOL: 266RFG-2525-22

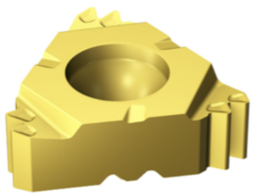


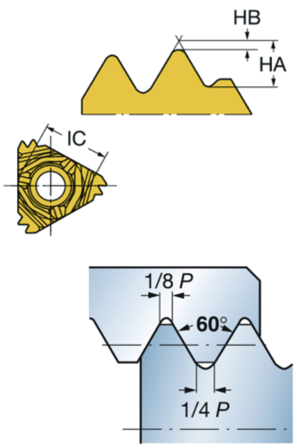
Specifiche dei prodotti — Metrica / Imperiale

Codice del tipo di bloccaggio (MTP)	**clamp with screw through hole**
Parte 2 identificativi interfaccia articoli da taglio (CUTINT_MASTER)	**CoroThread -external size 22 (266.RG-22)**
Angolo di spoglia inferiore assiale (ALP)	**-10 °**
Angolo di correzione elica della filettatura (THCA)	**1 °**
Interfaccia adattatore lato macchina (ADINTMS)	**Rectangular shank -metric: 25 x 25**
Angolo del corpo lato macchina (BAMS)	**0 °**
Sporgenza massima (OHX)	**33,3 mm**
Versione (HAND)	**Right**
Codice tipo ingresso refrigerante (CNSC)	**without coolant entry**
Larghezza dello stelo (B)	**25 mm**
Altezza dello stelo (H)	**25 mm**
Lunghezza funzionale (LF)	**150 mm**
Larghezza funzionale (WF)	**32 mm**

Figure 52: tool 266RFG-2525-22 and its specifications from the catalog "Sandvik"

INSERT: 266RG-22MM02A250E 1020





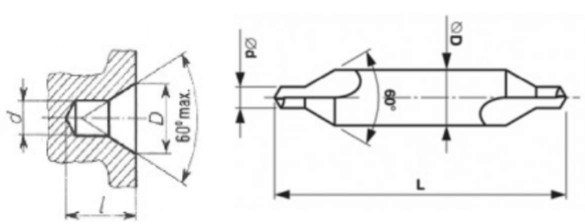
Specifiche dei prodotti — Metrica / Imperiale

Livello 1 di classificazione del materiale (TMC1ISO)	P M K N S
Geometria (CBMD)	**A**
Tipo forma della filettatura (THFT)	**M (Metric 60°)**
Numero standard (STDNO_1)	**ISO 965-1998**
Tipo di filetto (TTP)	**external**
Passo della filettatura (TP) ⓘ	**2,5 mm**
Tipo profilo della filettatura (TPT)	**full profile**
Numero di denti (NT)	**2**
Classe di tolleranza della filettatura (TCTR)	**IT 6**
Altezza teorica della filettatura (HA)	**1,87 mm**
Differenza altezza filettatura (HB)	**0,36 mm**
Distanza profilo EX (PDX)	**3,75 mm**
Distanza profilo EY (PDY)	**1,968 mm**

Figure 53: insert 266RG-22MM02A250E 1020 and its specifications from the catalog "Sandvik"

DRILLING

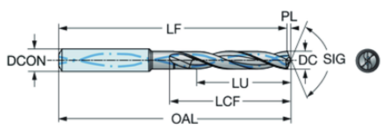
TOOL PILOT HOLE: 25922500500



Codice	d. punta	d. corpo	L totale	-	-	Prezzo
25922500500	5	12,5	63,5	-	-	23.00

Figure 54: tool 25922500500 and its specifications from the catalog "Ettebi"

TOOL: 860.1-0850-080°1-PM P1BM



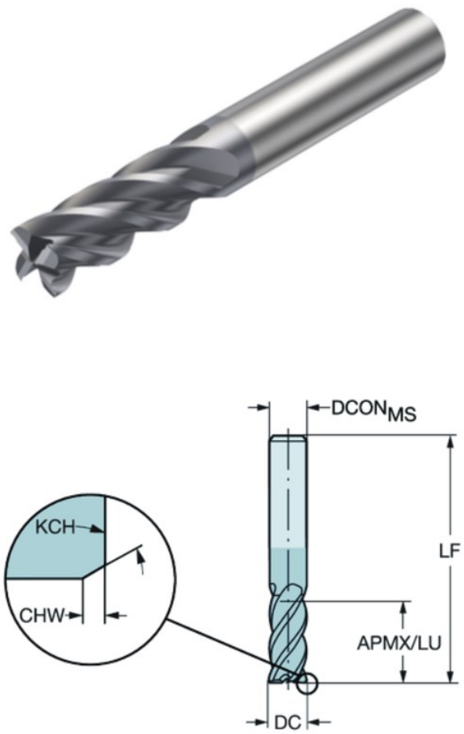
Specifiche dei prodotti

Metrica Imperiale

Livello 1 di classificazione del materiale (TMC1ISO)	P
Diametro di taglio (DC)	**8,5 mm**
Diametro di collegamento lato macchina (DCONMS)	**10 mm**
Lunghezza utile (LU)	**80 mm**
Tolleranza ottenibile del foro (TCHA)	**H8**
Rapporto lunghezza/diametro utile (ULDR)	**9,4118**
Angolo di spoglia superiore ortogonale (GAMO)	**17,72 °**
Numero di taglienti effettivi sulla faccia (ZEFF)	**2**
Interfaccia adattatore lato macchina (ADINTMS)	**Cylindrical shank (DIN6535-HA) -metric: 10**
Tolleranza diametro stelo (TCDCON)	**h6**

Figure 55: tool 860.1-0850-080°1-PM P1BM and its specifications from the catalog "Sandvik"

END MILL: 2P340-0900-PA 1630



Specifiche dei prodotti

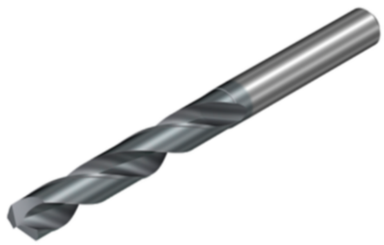
Metrica Imperiale

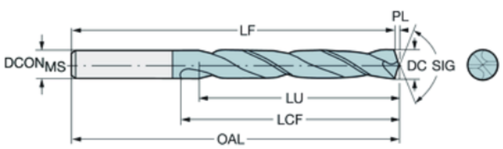
Livello 1 di classificazione del materiale (TMC1ISO)	P K
Diametro di taglio (DC)	**9 mm**
Angolo del tagliente dell'utensile (KAPR)	**90 °**
Classe di tolleranza diametro di taglio (TCDC)	**h10**
Superficie di contatto del diametro di taglio (DCF)	**8,7 mm**
Smusso angolare (KCH)	**45 °**
Larghezza dello smusso angolare (CHW)	**0,15 mm**
Profondità di taglio massima (APMX)	**19 mm**
Profondità di taglio massima (APMX_PFW)	**19 mm**
Center cutting capability (CCC)	**Sì**
Profondità di taglio massima (APMX_FFW)	**19 mm**
Lunghezza utile (LU)	**19 mm**
Numero di taglienti effettivi periferici (ZEFP)	**4**
Interfaccia adattatore lato macchina (ADINTMS)	**Cylindrical shank (DIN6535-HA) -metric: 10**
Angolo massimo lavorazione del piano inclinato (RMPX_FFW)	**5 °**

Figure 56: end mill 2P340-0900-PA 1630 and its specifications from the catalog "Sandvik"

DRILL

CARBIDE DRILL TIP: 462.1-0800-040°0-XM X2BM





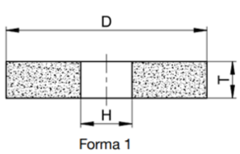
Specifiche dei prodotti — Metrica / Imperiale

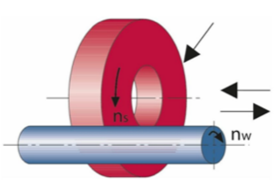
Livello 1 di classificazione del materiale (TMC1ISO)	P K N
Diametro di taglio (DC)	**8 mm**
Diametro di collegamento lato macchina (DCONMS)	**8 mm**
Lunghezza utile (LU)	**41,16 mm**
Tolleranza ottenibile del foro (TCHA)	**H9**
Rapporto lunghezza/diametro utile (ULDR)	**5,145**
Angolo di spoglia superiore ortogonale (GAMO)	**20,45 °**
Numero di taglienti effettivi sulla faccia (ZEFF)	**2**
Interfaccia adattatore lato macchina (ADINTMS)	**Cylindrical shank (DIN6535-HA) -metric: 8**
Tolleranza diametro stelo (TCDCON) ⓘ	**h6**
Qualità (GRADE)	**X2BM**
Substrato (SUBSTRATE)	**HC**
Rivestimento (COATING)	**PVD TiAlCrSiN**
Gruppo standard di base (BSG)	**DIN 6537 L**
Geometria (CBMD)	**XM**

Figure 57: carbide drill tip 462.1-0800-040°0-XM X2BM and its specifications from the catalog "Sandvik"

GRINDING

GRINDING WHEEL: 89A 802 J5A V217 50





Forma	N. tipo	DxTxH	PxF	Specifica	Vmax m/s	Nota
1	690785	300x40x76,2		89A 802 J5A V217 50	50	
	889228	400x20x127		89A 802 J5A V217 50	50	
	881114	400x25x127		89A 802 J5A V217 50	50	
	39869	400x30x127		89A 802 J5A V217 50	50	Grossezza del grano 80 Ra ca. 0,20–0,35 µm
	620118	400x40x127		89A 802 J5A V217 50	50	

Table 13: specifications of the grinding wheel 89A 802 J5A V217 50 from the catalog "Tyrolit"

89A 60 M 5 V 217

Indicazione del legante	Codice interno che definisce il tipo di legante
Legante	
V	Legante ceramico
B	Legante resinoide
E	Legante elastico
G	Legante galvanico
Struttura	Quanto più alto è il numero, tanto maggiore sarà la porosità della mola
Durezza	A lettera crescente corrisponde una durezza maggiore
G	Tenero
R	Duro
Descrizione della grossezza del grano	Indicazione del grano in mesh
14 – 36	GROSSA
46 – 60	MEDIA
80 – 220	FINE
800 – 1 200	MOLTO FINE
Descrizione degli abrasivi	
10A	Corindone normale
50A	Miscela di 89A e 10A
52A	Corindone semipregiato
80A	Miscela di 88A e corindone speciale
87A	Miscela di 89A e 88A
88A	Corindone rosa
89A	Corindone bianco
91A	Corindone rosso
92A	Miscela di 89A e corindone speciale
93A	Miscela di 89A e 91A
97A	Corindone speciale
454A	Miscela di corindone sinterizzato e 89A
455A	Miscela di corindone sinterizzato e 89A
C	Carburo di silicio verde
1C	Carburo di silicio nero
50C	Miscela di carburo di silicio verde/nero

Table 14: specifications of conventional ceramic grinding wheels from the catalog "Tyrolit"

TAP

TAPPING DRILL:

CARATTERISTICHE

- *HSS-CO*
- *Filettatura M metrica passo grosso*
- *Serie tre pezzi*
- *R≤ 1.200 N/mm²*
- *Tolleranza H6*
- *DIN 352*

Ø mm	P	/ mm	L mm	Cod. Ineco	Vecchio cod.	Imballo	Listino €
3,00	0,50	11,00	40,00	2780203X05	024.0103X05	1	21,050
4,00	0,70	13,00	45,00	2780204X07	024.0104X07	1	21,050
5,00	0,80	14,00	50,00	2780205X08	024.0105X08	1	21,750
6,00	1,00	16,00	56,00	2780206X1	024.0106X1	1	22,850
8,00	1,25	18,00	63,00	2780208X125	024.0108X125	1	25,150
10,00	1,50	24,00	70,00	2780210X15	024.0110X15	1	31,950

Table 15: tapping drills and their specifications from the catalog "Wurth"

CUTTING PARAMETERS

Constants:

Kronenberg's constant:

$$\frac{1}{n} = 0.197$$

tensile strength:

R_m=750 MPa

efficiency:

η= 70%

To select the initial parameters, we compared the tables found in the textbooks.

TURNING

FACING (SURF 1 E SURF 8)

insert angle:

ß=80°

starting diameter:

D = 30 mm

final diameter:

d = 0 mm

allowances to be removed:

h = 15 mm

length:

L = 15 mm

depth of cut:

ap= 1.5 mm

feed:

f = 0.15 mm

theoretical cutting speed:

vt = 40 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 424.6 rpm

we select the spindle speed closest to the value allowed by the machine = 410 rpm

spindle speed:

rpm= 410 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 38.62 m/min

chip section:

S= f*ap= 0.225 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 897.3 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 1203.8 N/ mm^2

cutting force:

Ft= $Pt * S$= 270.9 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.17 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.25 kW

n° passes= 1

ROUGHING (SURF5)

insert angle:

ß=80°

starting diameter:

D = 30 mm

final diameter:

d = 20 mm

allowances to be removed:

h = 5 mm

length:

L = 118 mm

depth of cut:

ap= 1.25 mm

feed:

f= 0.4 mm

theoretical cutting speed:

vt= 30 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 318.5 rpm

spindle speed:

rpm= 314 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 29.58 m/min

chip section:

S= f*ap= 0.5 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 897.3 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 1028.6 N/ mm^2

cutting force:

Ft= $Pt * S$= 524.3 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.25 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.36 kW

n° passes= 4

CHAMFER (SURF2)

insert angle:

ß=80°

starting diameter:

D = 20 mm

length:

L = 1 mm

depth of cut:

ap= 1 mm

feed:

f= 0.8 mm

theoretical cutting speed:

vt= 25 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 398.1 rpm

spindle speed:

rpm= 314 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 19.71 m/min

chip section:

S= f*ap= 0.8 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 897.3 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 937.6 N/ mm^2

cutting force:

Ft= $Pt * S$= 750 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.25 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.35 kW

n° passes= 1

FINISHING (SURF5)

insert angle:

ß=80°

starting diameter:

D = 20 mm

final diameter:

d = 18.2 mm

allowances to be removed:

h = 0.9 mm

length:

L = 117 mm

depth of cut:

ap= 0.3 mm

feed:

f= 0.2 mm

theoretical cutting speed:

vt= 40 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 636 rpm

spindle speed:

rpm= 550 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 34.54 m/min

chip section:

S= f*ap= 0.06 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 897.3 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 1561.9 N/ mm^2

cutting force:

Ft= $Pt * S$= 93.7 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.054 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.077 kW

n° passes= 3

GROOVE (SURF4)

insert angle:

ß=90°

starting diameter:

D = 18.2 mm

Final diameter:

d = 14.6 mm

allowances to be removed:

h = 1.8 mm

length:

L = 3.75 mm

depth of cut:

ap= 2.5 mm

feed:

f= 0.05 mm

theoretical cutting speed:

vt= 25 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 437.5 rpm

spindle speed:

rpm= 410 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 23.43 m/min

chip section:

S= f*ap= 0.125 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 971 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 1462 N/ mm^2

cutting force:

Ft= $Pt * S$= 182.7 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.07 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.1 kW

n° passes= 3

THREADING (SURF3)

insert angle:

ß=60°

starting diameter:

D = 18.2 mm

length:

L = 25 mm

depth of cut:

ap= 1.36 mm

feed:

f= 2.5

In threading the feed corresponds to the thread pitch

theoretical cutting speed:

vt= 8 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 140 rpm

spindle speed:

rpm= 117 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 6.69 m/min

chip section:

S= f*ap= 3.4 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 740.9 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 582.2 N/ mm^2

cutting force:

Ft= $Pt * S$= 1979.3 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.22 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.32 kW

n° passes= 6

DRILLING (SURF7)

insert angle:

ß=80°

starting diameter:

D = 9 mm

length:

L = 68 mm

depth of cut:

ap= 18 mm

feed:

f= 0.1

theoretical cutting speed:

vt= 20 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 749.3 rpm

spindle speed:

rpm= 700 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 18.68 m/min

chip section:

S= f*ap= 1.8 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 897.3 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 799.2 N/ mm^2

cutting force:

Ft= $Pt * S$= 1438.6 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.45 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.64 kW

n° passes= 2

TAP

Since the operation is manual, the machining parameters cannot be precisely estimated. However some considerations can be made: the rotation will occur at very **low speeds**, being controlled by the operator and the **feed** will **not be constant**, as frequent reversals are needed to evacuate the chips.

DRILL

DRILLING (SURF6)

insert angle:

ß=60°

hole diameter:

D = 8 mm

length:

L = 18 mm

depth of cut:

ap= 2.5 mm

feed:

f= 0.11 mm

theoretical cutting speed:

vt= 20 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$= 796.17 rpm

spindle speed:

rpm= 600 rpm

cutting speed:

vt= $\frac{\pi D*n}{1000}$ = 15.1 m/min

chip section:

S= f*ap= 0.22 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$= 722.88 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$= 974 N/ mm^2

torque:

C= $\frac{f*D^2*Pt}{8000}$ = 0.86 Nm

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$= 0.054 kW

power consumption:

Pa= $\frac{Pc}{\eta}$= 0.078 kW

MILLING

FACING (SURF10)

Values calculated for a face.

milling cutter diameter:

D = 9 mm

length:

L = 15 mm

number of teeth:

z = 4

depth of cut:

ap = 2 mm

feed per tooth:

fz = 0.04 mm

theoretical cutting speed:

vt = 12 m/min

theoretical spindle speed:

rpm= $\frac{vt*1000}{\pi D}$ = 425 rpm

spindle speed:

rpm= 384 rpm

cutting speed:

vt = $\frac{\pi D*n}{1000}$ = 10.85 m/min

milling feed:

Vf = 67.94 mm/min

chip section:

S = 0.08 mm^2

specific cutting pressure:

Ps= $2.4 * Rm^{0.454} * \beta^{0.666}$ = 971 N/ mm^2

cutting pressure:

Pt= $Ps * S^{\frac{-1}{n}}$ = 1596.27 N/ mm^2

cutting force:

Ft= $Pt * S$ = 510.8 N

cutting power:

Pc= $\frac{Ft*Vc}{60*1000}$ = 0.092 kW

power consumption:

Pa= $\frac{Pc}{\eta}$ = 0.132 kW

GRINDING

GRINDING (SURF5)

k = 7.5

grinding wheel diameter:

D = 400 mm

grinding wheel contact width:

s = 40 mm

Diameter of the piece:

d = 18.2 mm

length:

L = 89.25 mm

spindle speed:

rpm= 800 rpm

cutting speed:

vt= 16.75 m/min

peripheral cutting speed:

vp= 0.28 m/min

depth of cut:

ap = 0.05 mm

feed:

f = 0.8 mm

chip thickness:

S $=\frac{\sqrt{d*ap*2}}{10}$ 0.13 mm

material removal volume:

V $= S * f * ap = 0.005$ mm^3

cutting power:

P $=\frac{Ft*Vc}{60*1000}$= 0.023 kW

power consumption:

Pa $=\frac{Pc}{\eta}$= 0.033 kW

CALCULATION OF TIMES

The times necessary for executing the machining cycle can be divided into **active times, passive times** and **preparation times**, to make it easier we have included the preparation times with the passive.

PASSIVE TIMES

Passive times are portions of the cycle when **no machining takes place**, in our case these are the times needed to set up the machines, adjust the various alignments and changing tools or inserts. To study those, we divided the entire activity into sequences of simple actions and compared them to the standardized ones defined in the "standard time" tables found in our textbooks.

Operation	**T (min)**
FACING	
mounting the self-centering chuck	0.6
positioning the workpiece on the chuck and centering	0.5
mounting the facing tool per facing	0.5
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
CENTERING	
mounting the center drill	0.35
bringing the carriage closer	0.2
selecting spindle speed	0.18
selecting feed per revolution	0.18
bringing the tailstock closer	0.2
retracting the tailstock	0.2
starting the machine	0.05
stopping the machine	0.05
dismounting the center drill	0.5
ROUGHING	
mounting the tailstock center	0.4
mounting the piece between the chuck and the tailstock center	0.5

Operation	T (min)
mounting the roughing tool	0.5
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
checking dimensions with caliper	0.2
CHAMFER	
dismounting the tool	0.5
mounting the chamfer tool	0.5
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
checking dimensions with caliper	0.2
FINISHING	
dismounting the tool	0.5
mounting the finishing tool	0.5
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
checking dimensions with caliper	0.2
GROOVE	
dismounting the tool	0.5
mounting the groove tool	0.5

Operation	**T (min)**
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
checking dimensions with caliper	0.2
THREADING	
dismounting the tool	0.5
mounting the threading tool	0.5
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
checking dimensions with thread gauge	0.2
dismounting the tool	0.5
dismounting the tailstock center	0.4
remove the workpiece from the chuck	0.5
FACING	
positioning the workpiece on the chuck and centering	0.5
mounting the tool per facing	0.5
positioning the tool	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
CENTERING	
dismounting the tool	0.4

Operation	T (min)
mounting the center drill	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
DRILLING	
dismounting the center drill	0.4
drill holder mounting and dismounting on tailstock	0.4
selecting spindle speed	0.18
selecting feed per revolution	0.18
starting the machine	0.05
stopping the machine	0.05
remove the workpiece from the chuck	0.4
checking dimensions with caliper	0.2
cleaning the worktable	0.3
TAPPING	
mounting	0.3
dismounting	0.3
cleaning the worktable	0.3
checking dimensions	0.2
DRILL	
mounting the workpiece on the chuck	0.9
mounting the center drill	0.35
checking external dimensions with caliper	0.2
checking internal dimensions with caliper	0.25
starting the machine	0.05
selecting spindle speed	0.18
selecting feed per revolution	0.18

Operation	T (min)
starting the machine	0.05
stopping the machine	0.05
MILLING (6 faces)	
mounting the milling cutter on the tool holder	0.8
mounting the divider	1.2
mounting the tailstock center of the divider	o.4
mount the workpiece on the chuck of the divider	0.4
mount the workpiece on the tailstock center del divider	0.8
selecting spindle speed	0.18
Positioning the workpiece relative to the tool with slight contact	0.5*6= 3
selecting automatic feed	0.18
engaging automatic feed	0.05*6= 0.3
disengaging automatic feed	0.05*6= 0.3
rotate the divider (estimated based on workshop operation time)	0.4*5= 2
remove the workpiece from the chuck of the divider	0.9
remove the workpiece from the tailstock center of the divider	0.4
dismounting the milling cutter on the tool holder	0.8
checking dimensions with caliper	0.2
GRINDING	
mount the workpiece between centers	0.18
selecting axial feed	0.18
selecting spindle speed	0.18
bringing the grind wheel closer	0.15
starting the machine	0.05
stopping the machine	0.05
retracting the grind wheel	0.15
remove the workpiece	0.2

Table 16: standard passive times for our machining operations

ACTIVE TIMES

Active times are the times in the cycle during which relative movement occurs between the tool and the workpiece, **generating chips**. To calculate these we used the following fomulas:

- For Turning, Drilling:

$$Ta = \frac{e + L}{f * n} * n° \, of \, passes$$

- For Milling

$$Ta = \frac{e + L}{Vf} * n° \, of \, passes$$

e = extracorsa [mm]

L = length [mm]

For the tapping operation we estimate the time required to complete athread to be approximately 1.5 minutes.

	f	**spindle speed**	**Vf**	**n° passes**	**e (mm)**	**L (mm)**	**Active times (min)**
LATHE							
facing	0.15	410		1	2	15	0.553
centering							0.05
roughing	0.4	314		4	2	118	3.822
chamfer	0.8	314		1	2	1	0.012
finishing	0.2	550		3	2	117	3.245
groove	0.05	410		3	2	3.75	0.841
threading	2.5	117		6	2	25	0.554
facing	0.15	410		1	2	15	0.553
centering							0.05
drilling	0.1	700		2	2	68	2
TAPPING							
M10 hole							1.5
DRILLING							

	f	spindle speed	Vf	n° passes	e (mm)	L (mm)	Active times (min)
drilling	0.11	600		1	4	18	0.333
MILLING							
facing			67.94	6	2	15	1.50
GRINDING							
grinding	0.8	800		2	6	89.25	0.298

Table 17: calculation of active times for the various machining phases

SUMMARY TABLE

In the following table we have the previously estimated times and calculated the total time for each operation. According to our calculations, the production of a shaft requires approximately **53 minutes**.

OPERATION	ACTIVE TIMES	PASSIVE TIMES	TOTAL TIMES
facing	0.553	2.46 min	3.01 min
centering	0.05	1.91 min	1.96 min
roughing	3.822	2.46 min	6.28 min
chamfer	0.012	2.06 min	2.07 min
finishing	3.245	2.06 min	5.31 min
groove	0.841	2.06 min	2.90 min
threading	0.554	3.46 min	4.01 min
	10A	TOT	25.5 min
facing	0.553	1.86 min	2.14 min
centering	0.05	1.26 min	1.31 min
Drilling	2	2.16 min	4.16 min
	10B	TOT	7.61 min
lathe	**10**	**TOT**	**33.15min**
tapping	1.5 min	0.90 min	2.40 min
	20	**TOT**	**2.40 min**

OPERATION	ACTIVE TIMES	PASSIVE TIMES	TOTAL TIMES
drill	0.33 min	2.21 min	2.54 min
	30	**TOT**	**2.54 min**
Milling (6 faces)	1.50 min	11.86 min	13.36 min
	40	**TOT**	**13.36 min**
Grinding	0.298 min	1.14 min	1.44 min
	50	**TOT**	**1.44 min**

Table 18: total machining times

COSTS

MACHINES

To calculate the machinery costs a service life of 20 years is assumed and each machine is considered to operate 8 hours per day.

These are the calculations we made to amortize the cost of the various machines.

LATHE

Price of the machine: 21500€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60= 120000 min

$amm_{lathe/year}$= 1075€

$amm_{lathe/minutes}$=year/working minutes=0.00896€/min

MILLING MACHINE

Price of the machine: 30000€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60= 120000 min

$amm_{milling/year}$=1500€

$amm_{milling/minutes}$=year/working minutes=0.0125€/min

DRILL

Price of the machine: 4050€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60= 120000 min

$amm_{drill/year}$=202.5€

$amm_{drill/minutes}$=year/working minutes=0.0017€/min

GRINDING

Price of the machine: 9000€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60= 120000 min

$amm_{Grinding/year}$=450€

$amm_{Grinding/minutes}$=year/working minutes=0.0038€/min

EQUIPMENT

To estimate the equipment costs we applied the same hypothesis that we made for the machines.

DIVIDER

Price: 350€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60= 120000 min

$cost_{min}$= 0.00029 €/min

T-HANDLE TAP WRENCH

Price: 100€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60= 120000 min

$cost_{min}$ = 0.000083 €/min

ENERGY

To assess the impact of energy consumption on the machining cycle, we considered the average electricity cost, which in Italy is currently Cm= 0,15916 €/kWh. We related it to the average power absorbed by the various machines and their active times.

$$C = \frac{Pm * ta * Cm}{60}$$

LATHE

C=$\frac{0.31\ kW * 0.15916 \frac{€}{kW} * 11 min}{60}$ =0.009 €/min

MILLING

C=$\frac{0.79\ kW * 0.15916 \frac{€}{kW} * 1.5 min}{60}$ =0.003 €/min

DRILL

C=$\frac{0.076\ kW * 0.15916 \frac{€}{kW} * 0.33 min}{60}$ = $6.7*10^{-5}$ €/min

GRINDING

C=$\frac{0.033\ kW * 0.15916 \frac{€}{kW} * 0.30 min}{60}$ = $2.6*10^{-5}$ €/min

MAINTENANCE

For the maintenance of the machines, we estimated an annual cost of 500€ for each unit. This was then related to the total annual minutes of use to obtain the unit cost per minute.

$$Cmanut = \frac{500}{250gg * 20years * 60}$$

Lathe: 0.0017 €/min

Milling: 0.0017 €/min

Drill: 0.0017 €/min

Grinding: 0.0017 €/min

LABOR

For labor, we assumed an hourly cost of €25 per operator, resulting in a unit cost of €0.42 per minute.

TOTAL COSTS

The table shows the total costs per minute of each machine previously calculated. These values were then multiplied by the actual usage times of the machines; this way we have the unit production cost per piece.

			Tp+ta	**Cp(tp+ta)**
C_{lathe}	0.42+0.00896+0.009+0.0017	0.440€/min	33.15	14.58
$C_{milling}$	0.42+0.0125+0.003+0.0017+0.00029	0.417 €/min	13.36	5.58
C_{drill}	$0.42+0.0017+6.7*10^{-5}+0.0017$	0.424 €/min	2.54	1.07
$C_{grinding}$	$0.42+0.0038+2.6*10^{-5}+0.0017$	0.426 €/min	1.44	0.61
C_{tap}	0.42+0.000083	0.420 €/min	2.40	1.01
	TOT	**2.127 €/min**		**22.85 €/piece**

Table 19: calculations of the total costs of the machining operations

TOOLS

To estimate the quantity of tools needed to produce 140 pieces we calculated the lifespan of the inserts, assuming a useful life of each cutting edge of approximately 40-50 minutes.

CCMT 12 04 12-PR 4335

ROUGHING + CHAMFER + FACING

Processing time: 4.51 min/piece

Useful life: 45 min

Number of cutting edges: 2

Number of pieces for one insert= $\frac{useful\ life * num\ cutting\ edges}{processing\ time}$ =19.95

Replacement every 20 pieces

Number of inserts required=7

CP-25BR-2020-12

FINISHING

Processing time: 3.39 min/piece

Useful life: 40 min

Number of cutting edges: 4

Number of pieces for one insert= $\frac{useful\ life * num\ cutting\ edges}{processing\ time}$ =47.19

Replacement every 47 pieces

Number of inserts required=2.97=3

MAPL 3 080 1025

GROOVE

Processing time: 0,841 min/piece

Useful life: 40 min

Number of cutting edges: 2

Number of pieces for one insert=$\frac{useful\ life * num\ cutting\ edges}{processing\ time}$=95.12

Replacement every 95 pieces

Number of inserts required=2

266RG-22MM02A250E 1020

THREADING

Processing time: 0,554 min/piece Useful life: 40 min

Number of cutting edges: 3

Number of pieces for one insert=$\frac{useful\ life * num\ cutting\ edges}{processing\ time}$=216.6

Number of inserts required=1

860.1-0850-080A1-PM P1BM

INTERNAL HOLE

Processing time: 2 min/piece Useful life: 45 min

Number of cutting edges: 2

Number of pieces for one insert=$\frac{useful\ life * num\ cutting\ edges}{processing\ time}$=45

Replacement every 45 pieces

Number of inserts required=3

2P340-0900-PA 1630

MILLING

Processing time: 1,5 min/piece Useful life: 50 min

Number of cutting edges: 4

Number of pieces for one insert=$\frac{useful\ life * num\ cutting\ edges}{processing\ time}$=146

Number of inserts required=1

2P340-0900-PA 1630

DRILL

Processing time: 0,33 min/piece

Useful life: 40 min

Number of cutting edges: 2

Number of pieces for one insert=$\frac{useful\ life * num\ cutting\ edges}{processing\ time}$=242

Number of inserts required=1

The total cost of of tools and insert was determined by summing the purchase price of the various components. This value was than amortized over the total number of pieces produced, obtaining this way the unit cost per piece.

Operation	**Unit cost (€)**	**Quantity**	**Total cost**
Roughing tool	105.3	1	105.3€
Roughing insert	14.62	7	102.34€
Finishing tool	110.7	1	110.7€
Finishing insert	28.5	3	85.5€
Groove tool	93.6	1	93.6€
Groove insert	41.66	2	83.32€
Threading tool	177	1	177 €
Threading insert	57.38	1	57.38€
Preforo	23	1	23€
Hole	172	3	516€
Tap roughing	31.95	1	31.95€
Tap finishing	6.95	1	6.95€
Milling	139.04	1	139.04€

Operation	Unit cost (€)	Quantity	Total cost
Drill	55.93	1	55.93€
Mola	80	1	80€
	TOT		**1668€**
	TOT per piece		**11.91€**

Table 20: amortization of the total tool cost

MATERIAL

To estimate the cpost of the C40 steel bar, we chose as a starting blank a cylindrical bar with a diameter of 0,03 m and a length of 0,130 m, giving a volume of $9{,}189 \times 10^{-5}$ m^3. considering the density of C40 steel as 7850 kg/m^3, the mass of the bar is 0,721 kg. multiplying this mass by the material cost of 0,45 €/kg, we get the unit cost per bar of **0,33 €.**

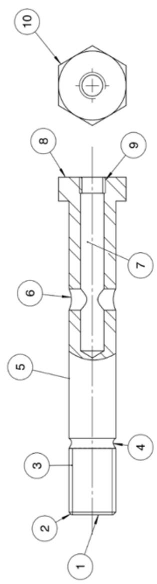
TOTAL COST

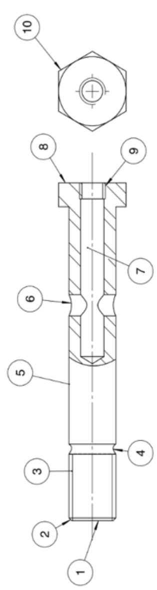
To determine the total cost of one shaft, we added together the tool cost, the machine cost and the material cost that we previously estimated. This way having an overall assessment of the unit production cost.

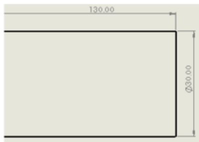
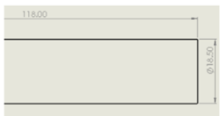
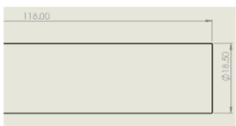
$C_{tot/piece}$= 22.85€ + 11.91€ + 0.33€= **35.1€/piece**

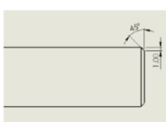
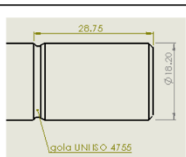
Therfore, the total cost of the whole required batch of 140 pieces is:

C_{tot}= 35.1€ * 140= **4912.6€**

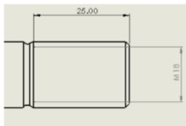
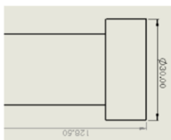
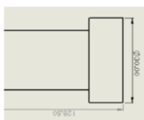
Università di Pisa Dip. di Ingegneria Per il Design Industriale			Production cycle: 7 Shaft		Students: DAWOOD MARG, VIALE IACOPO		Sheet 1 of 2
Surface designation	**Phase, Sub-phase, Operations**			**Machine**	**Equipment**	**Clamping face**	**Notes**
	10	A	facing surf. 1	Engine lathe	Self-centering chuck and tailstock	surface 10	
			centering 1				
			cylindrical turning (roughing) surf. 5				
			chamfer 45° surf. 2				
			cylindrical turning (finishing) surf. 5				
			groove external surf. 4				
			threading external 3				
		B	facing surf. 8			surface 3	
			centering and pilot hole 7				
			drilling 7				
	20		tapping surf. 9	Tap wrench	T-handle tap wrench	surface 3	
	30		centering 6	Column drill	Bench vise	surface 3	
			drilling 6				
	40		milling 1° face	Milling machine	Self-centering chuck, tailstock and divider	surface 3	
			divider rotation of 60° – 2° face				
			milling 2° face				

Università di Pisa Dip. di Ingegneria Per il Design Industriale		Production cycle: 7 Shaft		Students: DAWOOD MARG, VIALE IACOPO		Sheet 2 of 2
Surface designation	**Phase, Sub-phase, Operations**		**Machine**	**Equipment**	**Clamping face**	**Notes**
	40	divider rotation of 60° – 3° face	Milling machine	Self-centering chuck, tailstock and divider	surface 3	
		milling 3° face				
		divider rotation of 60° – 4° face				
		milling 4° face				
		divider rotation of 60° – 5° face				
		milling 5° face				
		divider rotation of 60° – 6° face				
		milling 6° face				
	50	grinding surf. 5	Cylinder grinder	Self-centering chuck and tailstock	surface 3	the tolerance to be obtained on the surface is Φ18 h6

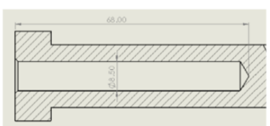
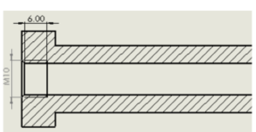
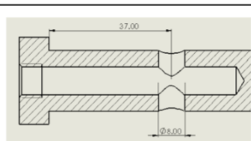
Università di Pisa Dip. di Ingegneria Per il Design Industriale				Phase of machining of the component: 7 Shaft		Students: DAWOOD MARG, VIALE IACOPO			Sheet 1 of 5
raw materials		Material: C40 steel Dimensions: Φ30mm L=130mm			Cutting parameters				
phase	machining sketch	operation		tool	P. machine (kW)	P. cutting	V. cutting	rpm	Notes
		n°	description		efficiency	n° passes	Depth of cut	Feed	
10A		1	facing surf. 1 from 130mm to 128.5mm	tool: SCLCR 2020K 12 insert: CCMT 12 04 12-PR 4335	7.45 0.7	0.17 1	38.6 1.5	410 0.15	
10A		2	centering surf. 1	Center drill					
10A		3	cylindrical turning (roughing) surf. 5 from Φ30 mm to Φ20 mm	tool: SCLCR 2020K 12 insert: CCMT 12 04 12-PR 4335	7.45 0.7	0.25 4	29.6 1.25	314 0.4	

Università di Pisa Dip. di Ingegneria Per il Design Industriale				Phase of machining of the component: 7 Shaft		Students: DAWOOD MARG, VIALE IACOPO			Sheet 2 of 5
raw materials		Material: C40 steel Dimensions: Φ30mm L=130mm			Cutting parameters				
phase	machining sketch	operation		tool	P. machine (kW)	P. cutting	V. cutting	rpm	Notes
		n°	description		efficiency	n° passes	Depth of cut	Feed	
10A		4	chamfer 45° surf. 2	tool: SCLCR 2020K 12 insert: CCMT 12 04 12-PR 4335	7.45 0.7	0.29 1	23.4 1	410 0.8	
10A		5	cylindrical turning (finishing) surf. 5 from Φ20 mm to Φ18.2 mm	tool: CP-25BR-2020-12 insert: CP-B1208D-MZ 4415	7.45 0.7	0.053 3	34.54 0.3	550 0.2	
10A		6	UNI ISO 4755 external groove	tool: SMALL O8C3 insert: MAPL 3 080 1025	7.45 0.7	0.07 3	23.4 2.5	410 0.05	

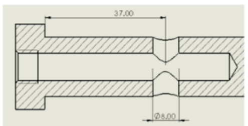
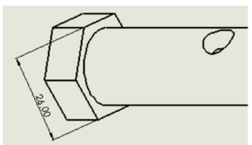
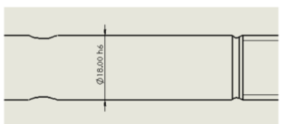
Università di Pisa Dip. di Ingegneria Per il Design Industriale	Phase of machining of the component: 7 Shaft	Students: DAWOOD MARG, VIALE IACOPO	Sheet 3 of 5

raw materials	Material: C40 steel Dimensions: Φ30mm L=130mm				Cutting parameters				
phase	machining sketch	operation n°	operation description	tool	P. machine (kW) efficiency	P. cutting n° passes	V. cutting Depth of cut	rpm Feed	Notes
10A		7	metric threading M18	tool: 266RRFG-2525-22 insert: 266RG-22MM02A250E 1020	7.45 0.7	0.22 6	6.68 1.36	117 2.5	
10B		8	facing surf. 8 from 128.5 mm to 127 mm	tool: SCLCR 2020K 12 insert: CCMT 12 04 12-PR 4335	7.45 0.7	0.17 1	38.6 1.5	410 0.15	
10B		9	centering and pilot hole surf. 8	Center drill and pilot drill					I make a pilot hole using a Φ5 mm drill bit.

Università di Pisa Dip. di Ingegneria Per il Design Industriale	Phase of machining of the component: 7 Shaft	Students: DAWOOD MARG, VIALE IACOPO	Sheet 4 of 5

raw materials	Material: C40 steel Dimensions: Φ30mm L=130mm				Cutting parameters				
phase	machining sketch	operation n°	operation description	tool	P. machine (kW) efficiency	P. cutting n° passes	V. cutting Depth of cut	rpm Feed	Notes
10B		10	blind hole Φ8.5 mm surf. 7	860.1-0850-080A1-PM P1BM	7.45 0.7	0.47 4	19.8 18/16	700 0.1	I perform 4 passes, increasing the depth: 2 passes at 16 mm and 2 passes at 18 mm. After each step, I withdraw the drill bit to evacuate the chips and apply lubricant.
20		11	manual tapping surf. 9	sgross: 2780210X15 fin: 2790610X1	The rotation is performed at a very low speed, controlled by the operator. The feed is not constant, as frequent reversals are needed to evacuate the chips.				I first use a roughing tap and then switch to a finishing tap.
30		12	centering surf. 8	Center drill					

Università di Pisa Dip. di Ingegneria Per il Design Industriale	Phase of machining of the component: 7 Shaft	Students: DAWOOD MARG, VIALE IACOPO	Sheet 5 of 5
raw materials	Material: C40 steel Dimensions: Φ30mm L=130mm	Cutting parameters	

phase	machining sketch	operation n°	operation description	tool	P. machine (kW)	P. cutting	V. cutting	rpm	Notes
					efficiency	n° passes	Depth of cut	Feed	
30		13	Through hole Φ8 mm perpendicular to the axis of surf. 6	462.1-0800-040A0-XM X2BM	2.2 0.7	0.053 -	15.1 -	600 0.11	
40		14	Facing one surface of the hexagonal head.	2P340-0900-PA 1630	3 0.8	0.092 -	10.85 2	384 0.04	Rotate the workpiece by 120° using the rotary table and repeat the operation for the remaining faces.
50		15	grinding surf. 5	89A 802 J5A V217 50	7.5 0.85	0.01 2	16.75 0.05	800 0.8	

METAL FORMING

The trolley wheel component we have chosen to manufacture using a **metal forming process** is the **Plate**, part **no. 2**.

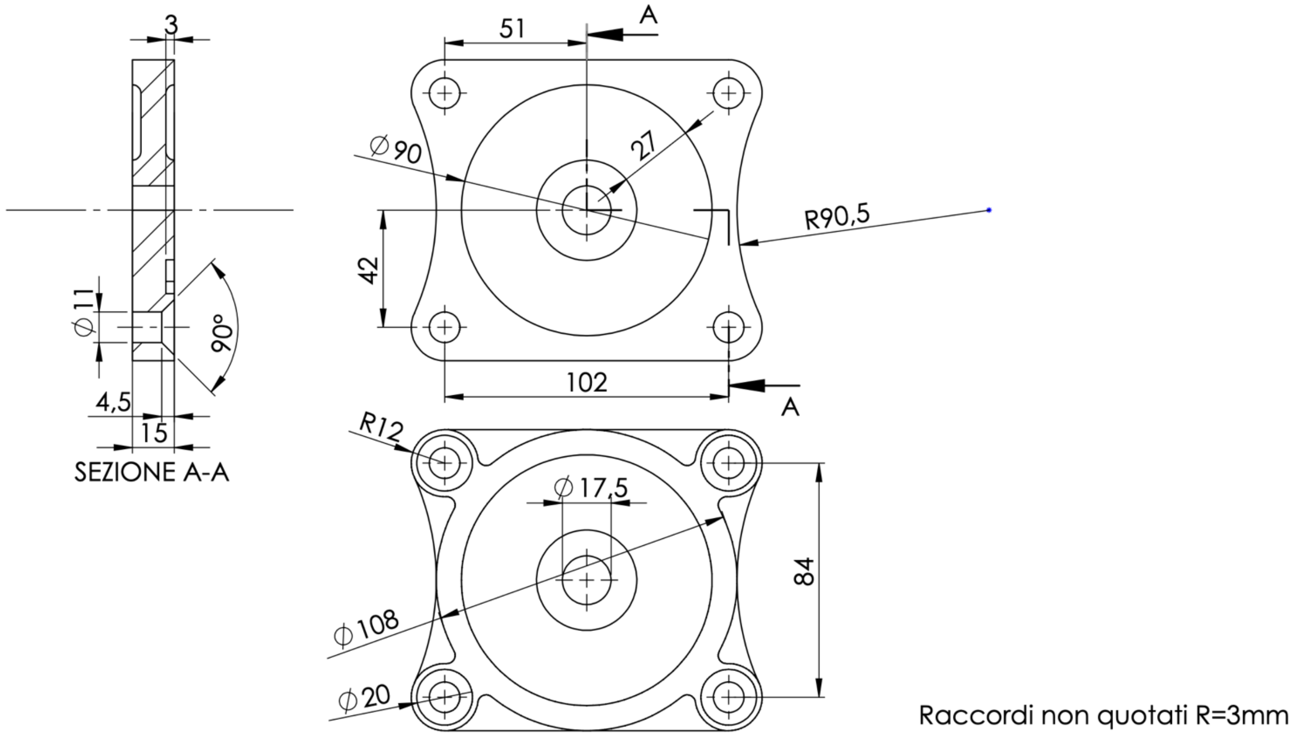


Figure 58: technical drawing of the "Plate"

PROCESS SELECTION

After analyzing the available processes, we decided to adopt **stamping**. This involves forcing, through compression, a metal workpiece to fill the cavity formed between two halves of a die recreating the desired part.
It is preferably performed **hot** to reduce the required forming forces, and the stamped parts exhibit excellent mechanical properties because they retain the fibrous structure of the rolled material.

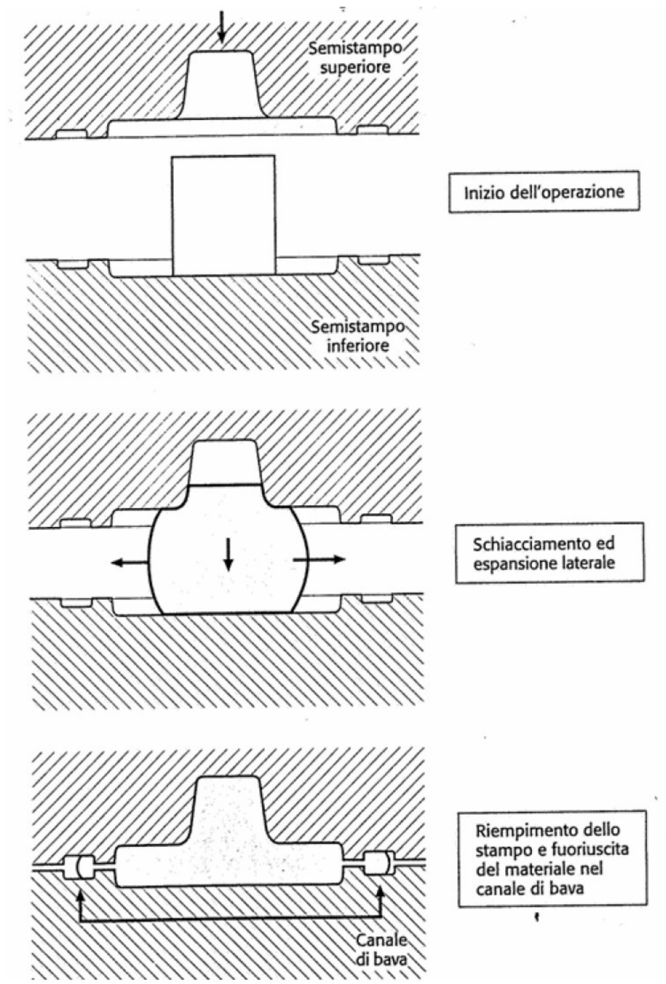


Figure 59: phases of the stamping process "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

We also considered other options such as cold forming and forging, but they proved unsuitable: the large thickness of our piece (15 mm) makes forging unfeasible, and cold forming would require excessive forces with high risk of material cracking.

Following these considerations we decided on a solution that integrates the forming of the geometry and creating the holes directly during the stamping process. The resulting holes will not have the same quality of those produced with blanking, but given the thickness, they will later be finished using machine tools.

FLASH PLANE SELECTION

As the **flash plane** we selected the **horizontal plane**, parallel to the upper surface of the part and passing through its geometric center, as the flash plane.

This choice avoids undercuts, facilitating both the manufacture of the die and the extraction of the part.

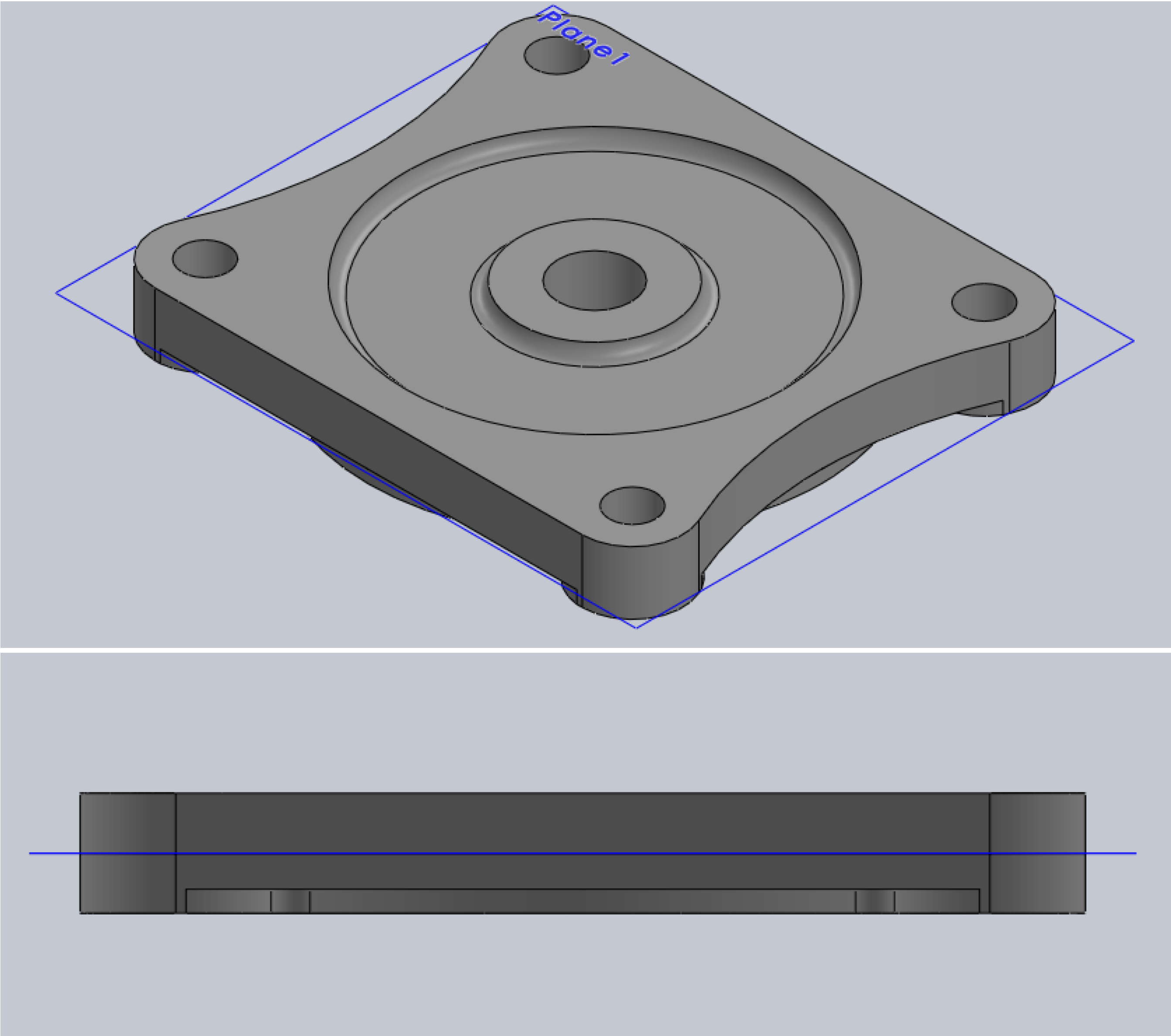


Figure 60: 3D view of the flash plane selection

MACHINING ALLOWANCES

We added **machining allowances** to enable subsequent finishing operations by chip removal, ensuring that the functional surfaces achieve the required geometric and quality properties.

They also compensate thermal shrinkage occurring during material cooling and balance the losses due to hot oxidation.

Dimensioni nominali (mm)	Lunghezza del pezzo (mm)			
	≤ 100	100 ÷ 300	300 ÷ 500	500 ÷ 1000
≤ 50	1,8 ÷ 2,3	1,8 ÷ 2,3	2,3 ÷ 3,1	3 ÷ 3,4
50 ÷ 75	2 ÷ 3	2 ÷ 3	2,5 ÷ 3	3,5 ÷ 4
75 ÷ 100	2 ÷ 3,5	2 ÷ 3,5	3 ÷ 3,5	3,5 ÷ 4,5
100 ÷ 400	3 ÷ 3,5	3 ÷ 4	3,5 ÷ 4,5	4,5 ÷ 5
400 ÷ 800	4 ÷ 4,5	4 ÷ 5	4,5 ÷ 5	5 ÷ 5,5
800 ÷ 1000	4 ÷ 5	4,5 ÷ 5,5	5,5 ÷ 6	5 ÷ 6,5

Table 21: values of machining allowances on metal forming blanks "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

We used the values indicated on the table from the textbook "*Giusti-Santochi*", in our piece all the nominal dimensions are less than 400 mm and the length of the part is less than 300 mm, therefore, to ensure tolerances and surface finishes, we added a **3mm layer of machining allowance** on the surface parts.

DRAFT ANGLES

To facilitate the removal of the part from the die and ensure proper die filling, we decided to add **draft angles** to the surfaces that would otherwise be **perpendicular** to the **parting plane**.

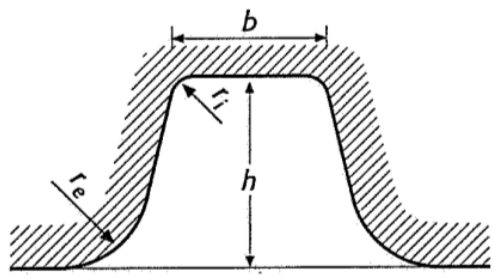
Profondità della caratteristica	Spessore minimo/angolo di spoglia			
6,35 mm	<1 mm / 0,5°			
13 mm	<1 mm / 1°	<1,5 mm / 0,5°		
19 mm	<1 mm / 2°	<1,5 mm / 1°	<2 mm / 0,5°	
25 mm		<1,5 mm / 2°	<2 mm / 1°	<2,5 mm / 0,5°
38 mm			<2 mm / 2°	<2,5 mm / 1°
51 mm				<2,5 mm / 2°

Table 22: indicative draft angle values

Considering the part thickness, which ranges between 13 mm and 19 mm, a **draft angle of 1°** was selected. This value ensures easy ejection of the part from the die during the metal forming process, minimizing the risk of surface defects or damage to the component.

FILLET RADII

Fillet radii promote proper plastic flow of the material within the die cavity, ensuring a more uniform and complete filling. At the same time, the elimination of sharp edges reduces stress concentrations in both the die and the finished part, improving mechanical performance and minimizing the risk of cracks or surface defects.



h/b	r_i (mm)	r_e (mm)
≤ 2	0,06h + 0,5	$2{,}5r_i + 0{,}75$
2 ÷ 4	0,07h + 0,6	$3r_i + 0{,}75$
> 4	0,08h + 0,75	$3{,}5r_i + 0{,}75$

Table 23: minimum values for fillet radii on metal forming blanks "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

In our part the ratio is h/b≈0,56, this puts us in the first row of the reference table. Therefore:

internal radius:

ri=0.06*15+0.5=1.4 mm

external radius:

re=2.5*ri+0.75= 4.25mm

STAMPING BLANK DESIGN

Below is the modified blank adapted for the metal forming process:

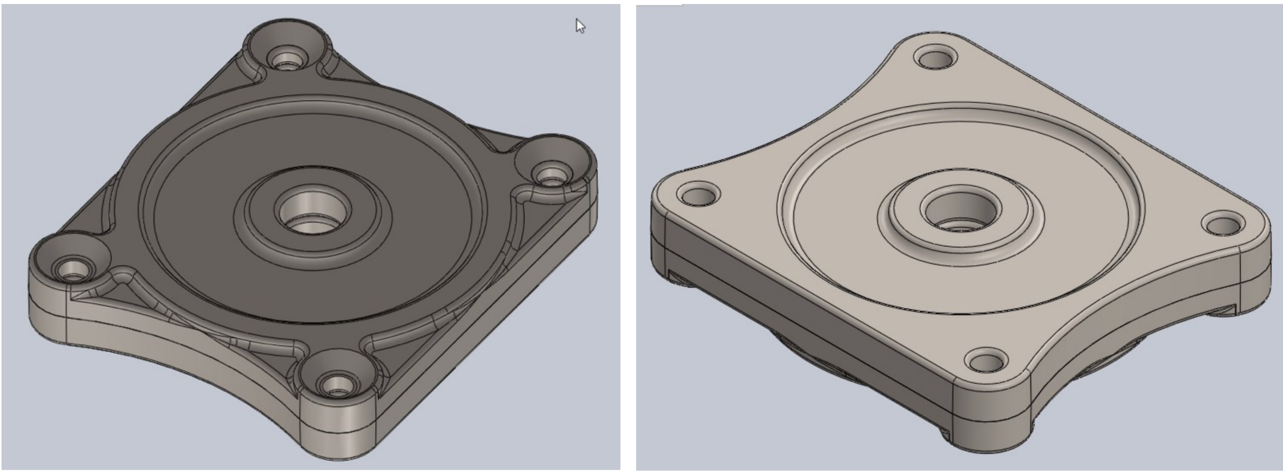


Figure 61: 3D model of the "Plate" with the changes made for the stamping process

MATERIAL SELECTION

For our piece we chose **42CrMo4 steel**, a chromium-molybdenum alloy widely used in mechanical applications.

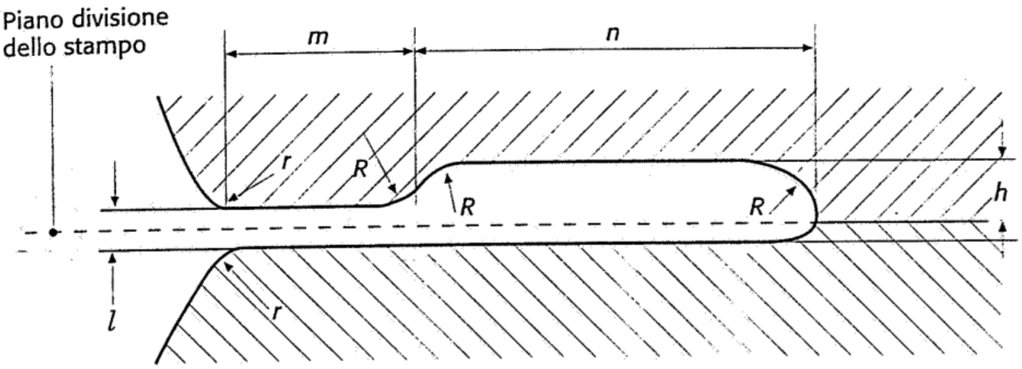
This material provides high mechanical strength, reaching approximately 1000 MPa after heat treatment, and excellent toughness, allowing it to withstand impacts and dynamic loads without critical deformation.
Moreover, 42CrMo4 offers good hot workability, effectively formable within a temperature range of 1100 °C to 800 °C, and can be easily finished with minor machining operations without compromising its mechanical properties.

GATING CHANNEL DIMENSIONING

During compression, the excess material flows into **the gating channel**, where, due to its reduced thickness, it cools rapidly and loses part of its plasticity.

Additionally, the gating channel serves to allow trapped air to escape through appropriately designed grooves and to cushion impacts between the two mold halves, thereby reducing wear and the risk of breakage.

We used the following table as a reference for sizing the channel:



l (mm)	h (mm)	r (mm)	m (mm)	n (mm)
0,6	3,3	1	6	18
0,8	3,4	1	6	20
1	3,5	1	7	22
1,6	4,3	1	8	22
2	5	1,5	9	25
3	6,5	1,5	10	28
4	8	2	11	30
5	9,5	2	12	32
6	11	2,5	13	35
8	14	3	14	38
10	17	3	15	40

$R \cong (2{,}5 \div 3)r + 0{,}5$; $l = 0{,}0175\sqrt{A}$; A = area dell'impronta del pezzo misurata sul piano di bava.

Table 24: gating channel dimensions "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

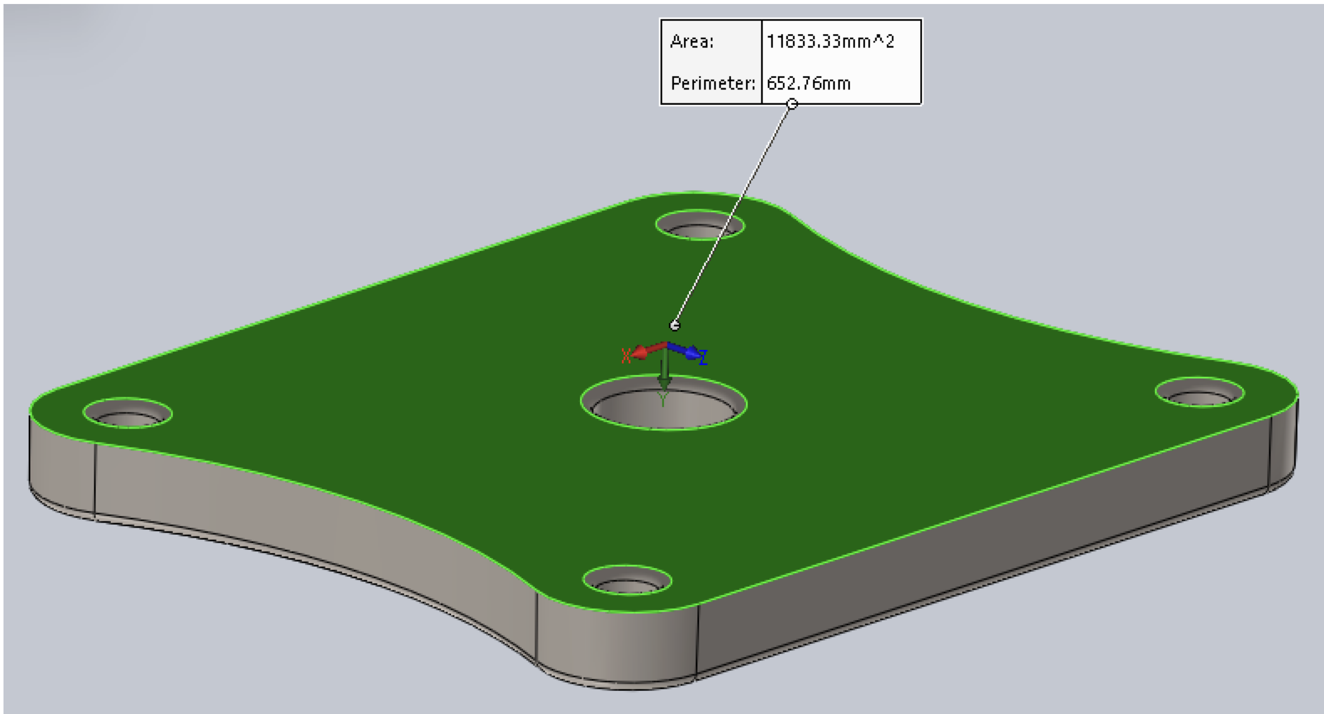


Figure 62: 3D view imprint area of the part on the gating plane

Imprint area of the part on the gating plane:

$A=11833.33\ mm^2$

$l= 0.0175\sqrt{A}=1.904= 2$ mm

from the reference table i get:

h= 5 mm r= 1.5 mm

m= 9 mm n= 25 mm

R= (2.5÷3) r+0.5= 4.25 mm

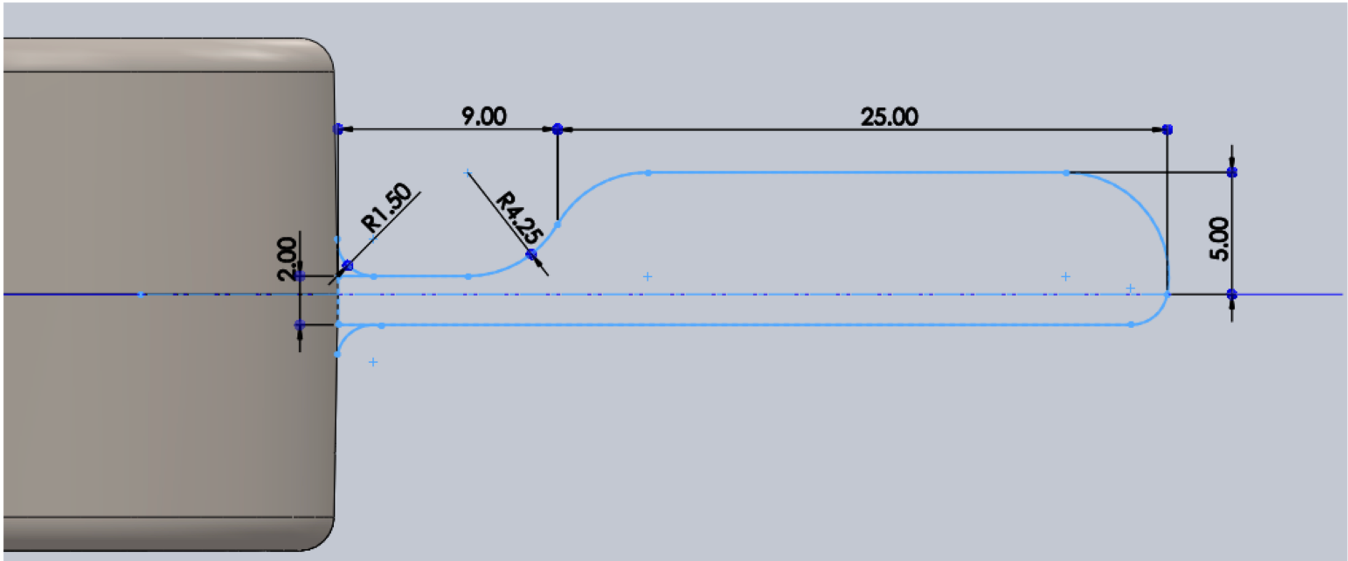
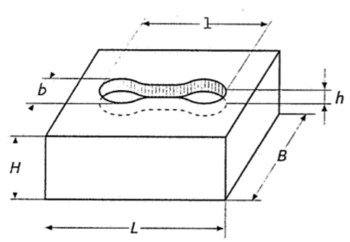


Figure 63: mesurments and dimensions of our gating channel

DIE

DIE DIMENSIONING



$$L = l \cdot f_l \qquad H = h \cdot f_h \qquad B = b \cdot f_b$$

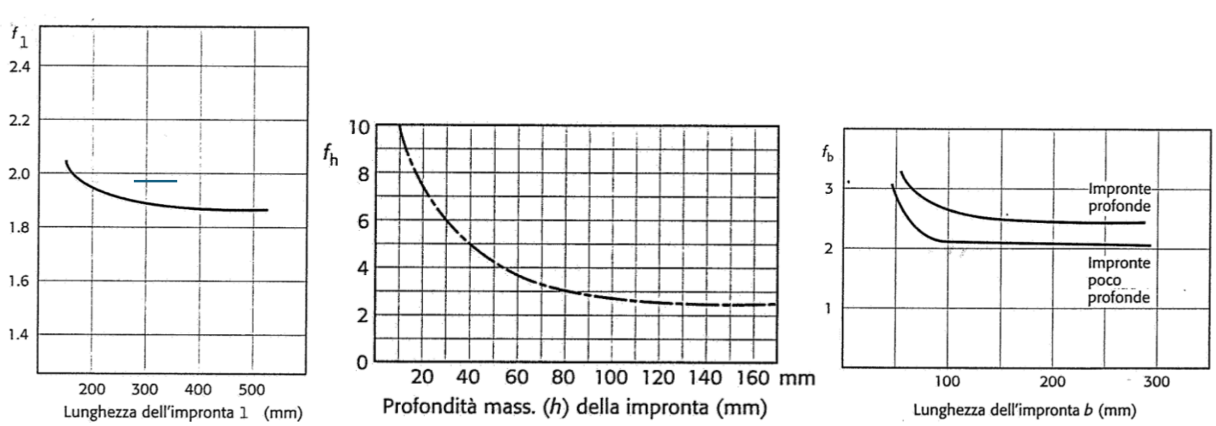


Figure 64: graphs used for the die dimensions "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

Starting from the dimensions of the workpiece (**length, width and height**), it is possible to obtain, using the reference charts the parameters **fl, fb e fh**. Afterwords using the indicated formulas, these values allow the determination of the final die dimension (**L, B, H**):

l= 108	b=125.5	h= 21
fl=2.1	fb=2.1	fh=7.6
L=226.8	B=263.55	H=159.6

TECHNICAL DRAWIND OF THE DIE

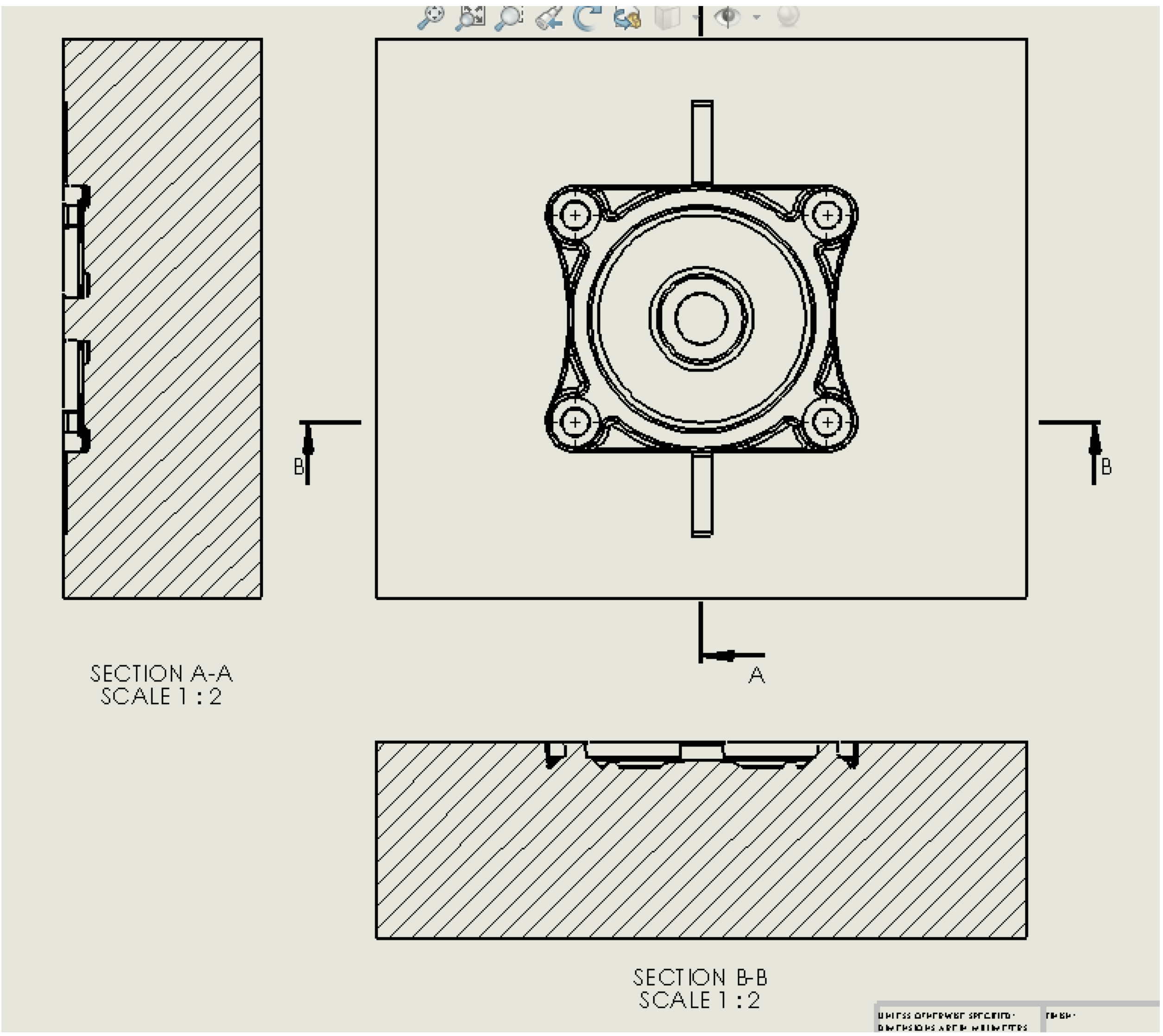


Figure 65: technical drawing of the die used to produce the "Plate"

SELECTION OF THE PRESS

We chose to produce our part using a **hydraulic press**.

Its operation is based on pressurized oil moving hydraulic pistons, ensuring a constant and uniform force throughout the entire work cycle.

This type of press allows for easy adjustment of the working speed and can generate very high forces, making it ideal for heavy-duty operations and for parts with substantial thickness like ours.

OPERATION DIAGRAM

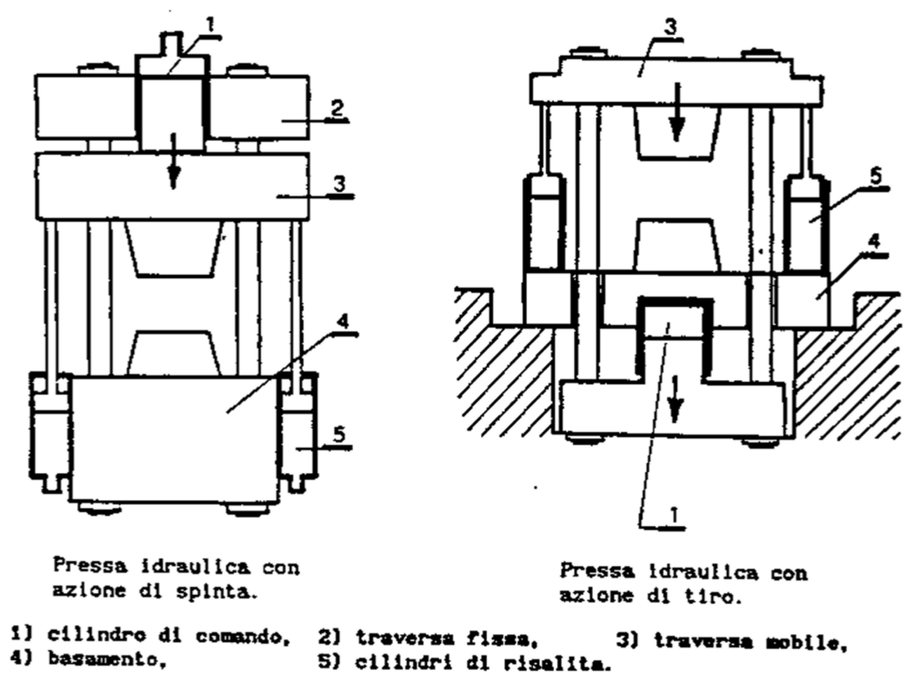


Figure 66: operation diagram of a press "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

Figure 67: hydraulic press Tigermetal 200 t

For this component, we chose the **Tigermetal 200-ton** hydraulic press, which is equipped with a dual hydraulic pump system, providing precise force control through the electric pump along with an additional manual pump.

SPECIFICATIONS

Motor	[kW]	7.5
Voltage	[V]	400
Lift	[mm]	400
Oil pump	[L/min]	21
Nominal pressure	[kN]	1850
Maximum working pressure	[bar]	320
Loading speed	[mm/s]	12
Descent speed	[mm/s]	8

Table 25: specifications of the hydraulic press Tigermetal 200 t

OPERATION PARAMETERS

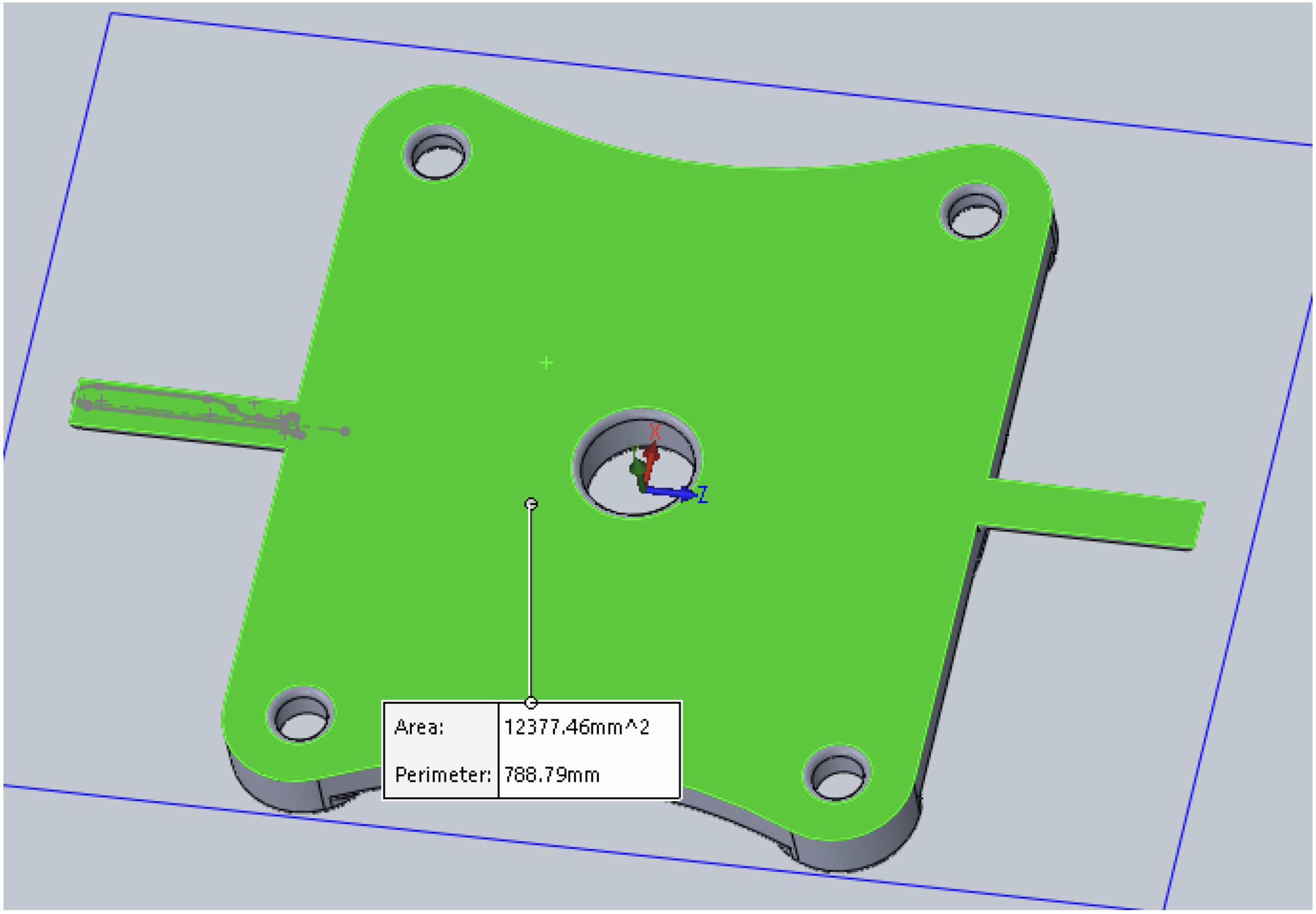


Figure 68: 3D view imprint area of the part on the gating plane

Volume of the piece:

V= 217215.2 mm^3

Imprint area of the part on the gating plane:

Ab=12377.46 mm^2= 0.01237746 m^2

Medium height:

$h_m=\frac{V}{Ab}$ = 17.55mm= 0.01755m

height of the piece:

h_0= 21mm

avarage strain:

$\varepsilon_m=\ln\left(\frac{h0}{hm}\right)$ =0.179

avarage strain speed:

$\varepsilon=\frac{v}{hm}$= 2.85

v = press ram descent speed

using the table as referance we chose v= 0.05 m/s.

Macchina	Energia disponibile (kN · m)	Forza disponibile (t)	Velocità media (m/s)
Maglio a semplice effetto	40-100		4-5
Maglio a doppio effetto	50-250		5-8
Maglio a contraccolpo	200-2000		4-10
Pressa a vite		50-2000	0,5-1
Pressa oleodinamica		300-30 000	0,05-0,30
Pressa a eccentrico		1000-10 000	0,05-1,5

Table 26: typical performance of dies and presses "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

Medium flow stress:

θ_f= C* ε^m=86.3

In which C=70 and m=0.2

Materiale	Temperatura (°C)	*C* (Mpa)	*m*
Leghe di Al	200-500	300-40	0,05-0,02
Leghe di Cu	200-800	400-20	0,02-0,3
Acciai			
• bassa % C	900-1200	170-50	0,08-0,20
• media % C	900-1200	180-55	0,07-0,25
• inossidabili	600-1200	420-40	0,02-0,4

Table 27: values used for the parameters C and m "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

Formin force:

P=K* θ_f *A= 7.4 kN

K = a constant that accounts for the complexity of the part and is normally between 3 and 12.

We consider an intermediate value K=7.

TIMES AND COSTS ANALYSIS

ESTIMATED TIMES

PHASE	**TIME [min]**
Positioning the workpiece	0.1
Press cycle (closing + hit + opening)	1.5
Ejection and visual inspection	0.15
Hot trimming (flash)	0.5
TOT per piece	2.25 min
TOT batch	315 min

Table 28: estimated values for working times

COSTS

PRESS

We estimated a service life of 20 years for the press, with daily usage in the workshop of 8 hours over a total of 250 working days per year. The cost has therefore been amortized as follows:

Price: 18683€ Daily work hours: 8h

Working minutes in a year: 250gg*8h*60=39600

Service life: 20 anni

$cost_{press/year}$=934€

$cost_{press/minutes}$=year/working minutes= 0.02359€/min

Cost$_{machineperpiece}$= 0.053€

Cost$_{machineperbatch}$= 7.43€

LABOR

For the labor we estimated an houarly cost of 25€/h for each worker, this means a unit cost per minute of 0.42€/min.

Cost$_{laborperpiece}$= 0.95€

Cost$_{laborperbatch}$= 132.3€

MATERIAL

we chose for our piece the 42CrMo4 steel, which has a price of 0.95€/Kg. we made these calculations:

Density: 7.85g/cm^3

Volume=217215.26 mm^3= 217.22 cm^3

Weight of the piece=1705.2g=1.7 kg

Cost$_{materialperpiece}$= 1.615€

Cost$_{materialperbatch}$= 226.10€

DIE

The die was made using H13 steel, which has a price of 6€/Kg. we applied the same thinking process used for the material costs:

Density= 7.8 g/cm^3

V=264*227*160=9588480 mm3= 9588,48 cm3

Mass = 74790g= 72.79kg

Cost$_{die}$= 436.74€

In addition, mechanical operations, treatments and other processes will be carried out to increase the durability and quality of the die, this being said we consider an additional cost of approximately 1200€.

$Tot_{diecost}$ =1.636.74€

$Cost_{dieperpiece}$= 11.69€

TOTAL COST PER PIECE

C_{tot}=0.053€+0.95€+1.615€+11.69€= 14.30€

WELDING

The welding will be performed between the M12 ISO 8678 screw of class 4.8, made from low-carbon steel, and the frame (previously produced via casting) in C45 steel. This material is weldable but requires certain precautions to avoid crack formation. Therefore, due to both the material type and the frame thickness of 15 mm, the piece must be preheated.

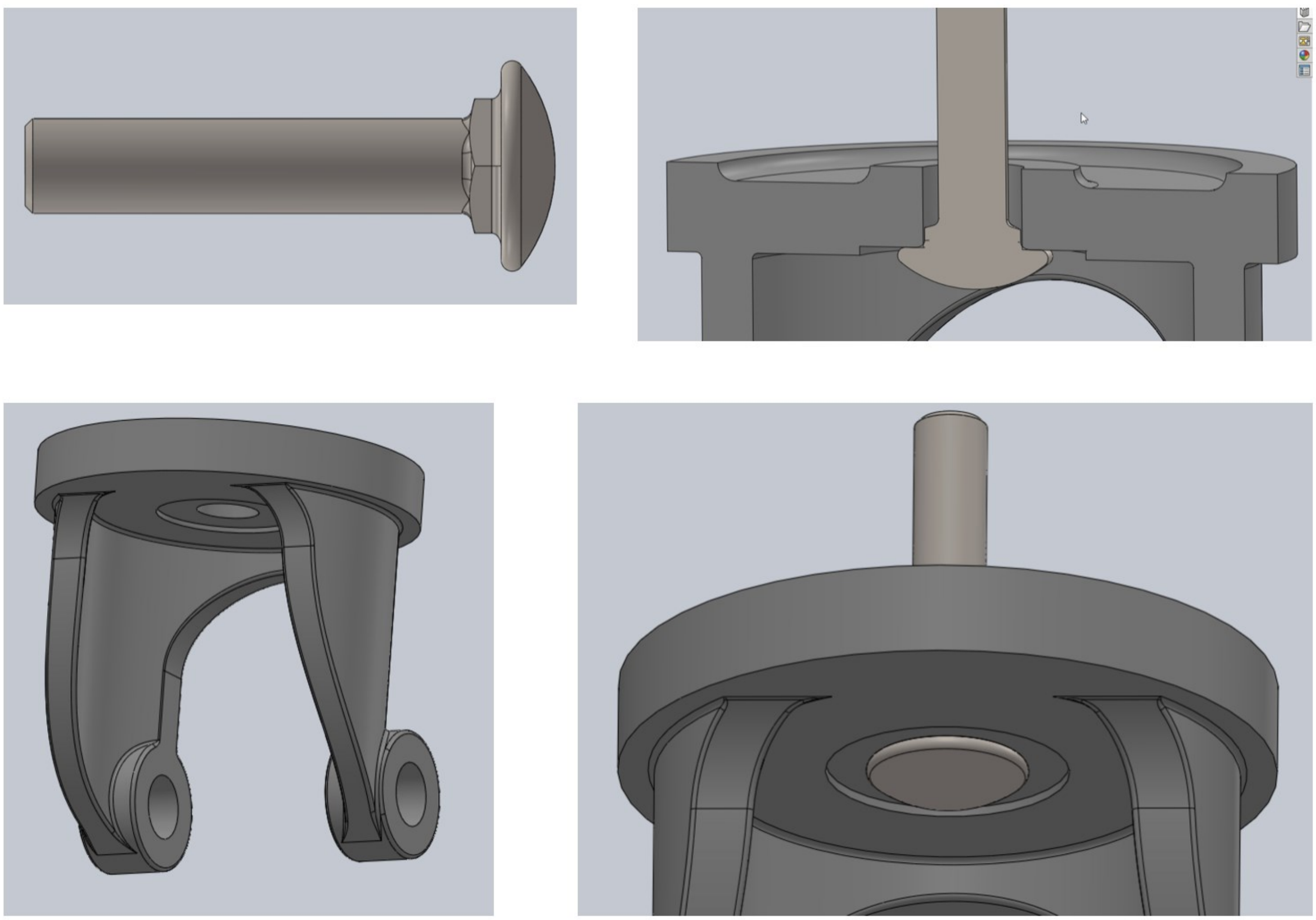


Figure 69: 3D models of the "frame" and the "screw"

We chose the **GMAW (MIG/MAG) welding process**, a technology that uses a continuous consumable wire electrode, protected by a gas flow (inert or active) delivered through a welding torch.

We opted for the **MAG** variant which uses active gas, proving to be the most suitable solution for our requirements.

The main advantages of this process are:

- High productivity, since the metal wire serves simultaneously as both the electrode and the filler material, ensuring continuous
- The ability to choose wires of different diameters, allowing welding on varying material thicknesses
- High process speed, combined with consistently reliable quality results
- Excellent adaptability to mechanized or fully automated welding systems

In addition to these aspects, the relatively low cost of equipment and materials makes MIG/MAG welding not only technically effective but also economically advantageous.

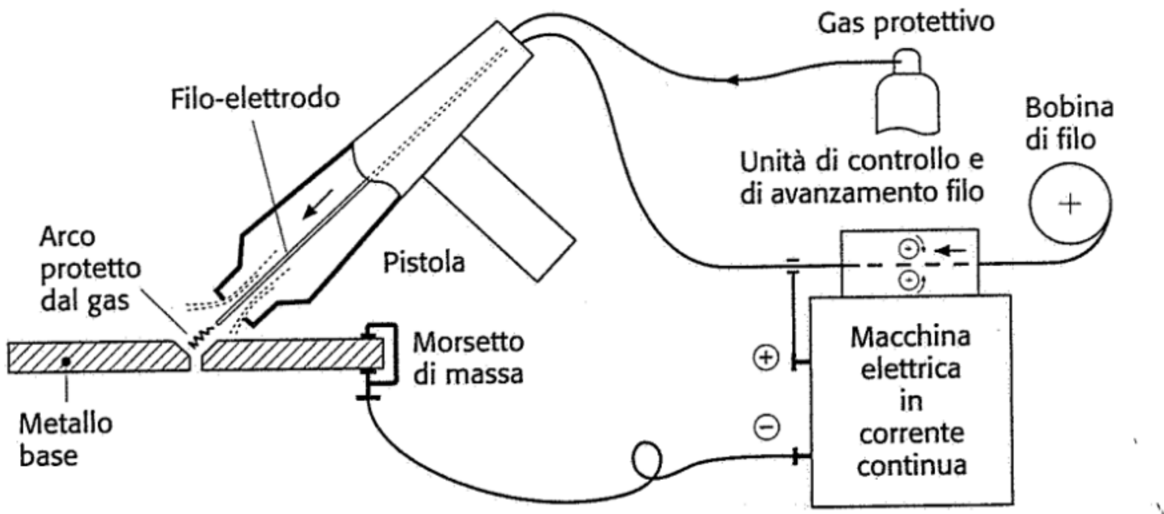


Figure 70: diagram of the GMAW welding setup "Tecnologia meccanica e studio di fabbricazione – Santochi, Giusti"

MACHINE

TELWIN TECHNOMIG 260 DUAL SYNERGIC | MULTI-PROCESS WELDER (MMA, MIG MAG, TIG)

Figure 71: multi-process welder Telwin Technomig 260 dual synergic

SPECIFICATIONS

Supply voltage	[Hz]	50-60
Wire thickness	[mm]	0.6-1.2
Adjustment range	[A]	20-250
Current draw	[kW]	3.3
Usable spool diameter	[mm]	200 e 300

Table 29: specifications of the welder Telwin Technomig 260 dual synergic

PARAMETERS

For our MAG welding process, the power supply is set to **direct current** with **reverse polarity**. Considering the large thickness of the pieces to be joined, the most suitable metal transfer mode is **spray arc**, which ensures uniform deposition, regular weld beads, and minimal spatter formation.

For the shielding gas, among the commonly used (Ar–CO_2, Ar–O_2 o Ar–CO_2–O_2), we selected one composed of **80% Argon and15% CO_2**.

As filler material, we chose **ER70S-6** (SG2), a copper coated wire suitable for welding under pure CO_2 or Ar/CO_2 mixtures on carbon steels. This wire offers high efficiency, excellent operability even in different positions, superior bead appearance, low spatter, and minimal silicate inclusions.

Figure 72: welding wire spool Telwin 15kg 1.0 mm

Welding wire diameter: 1 mm

Current: 210A

Voltage: 25V

Stickout: 15mm

Wire feed speed: 9m/min

A circular weld bead will be made around the head of the bolt.

TIMES AND COSTS

TIMES

Operation	**Time [min]**
Preparation of workpiece	0.5
Preheating piece	1
Positioning the screw	0.5
Welding	1.5
Cooling	1
Control	0.8
TOT PER PIECE	**5.3 min**
TOT PER BATCH	**742 min**

Table 30: estimated times for welding

COSTS

MACHINE

We have estimated a service life of 10 years for the welder. In the workshop, it is used 8 hours per day for a total of 250 working days per year. The purchase cost has therefore been amortized as follows:

Price of the machine: 11970€

Daily work hours: 8h

Working minutes in a year: 250gg*8h*60=39600

Service life: 10 years

$cost_{welder/year=}$1197€

$cost_{welder/minutes}$=year/working minutes= 0.030€/min

$Cost_{machineperpiece}$= 0.16€

$Cost_{machineperbatch}$= 22.26€

LABOR

For labor, we assumed an hourly cost of €25 per operator, resulting in a unit cost of €0.42 per minute.

$Cost_{laborperpiece}$= 2.23€

$Cost_{laborperbatch}$= 311.6€

EQUIPMENT

Welding material:

welding wire spool 5kg: 26€

Active gas:

shielding gas cylinder: 129€

C= 129€+26€= 155€

$Cost_{perpiece}$= 1.1€

TOTAL COST PER PIECE

C_{tot}=0.16€+2.23€+1.1€= 3.50€

METROLOGY

STANDARDS

Measuring all parts would be too costly, so it is necessary to establish a sampling method, varying it according to the type of parts to be measured.

To perform correct sampling, we referred to "*ISO 2859-1*", analyzing six parameters:

- Batch size
- Criticality: is it a critical dimension or not
- AQL (Acceptable quality level): strict, standard or lenient (A = acceptable defects | R = defects requiring rework)
- Whether the production process is stable and controlled
- Whether the measurements are expansive or time-consuming
- Customer requirements

ISO 2859-1 - Livelli di ispezione e AQL

Lotto	Cod.	Livello	Campioni	AQL 0.65 A/R	AQL 1.0 A/R	AQL 2.5 A/R
2-8	A	I	2	0/1	0/1	0/1
		II	2	0/1	0/1	0/1
		III	3	0/1	0/1	0/1
9-15	B	I	2	0/1	0/1	0/1
		II	3	0/1	0/1	0/1
		III	5	0/1	0/1	0/1
16-25	C	I	3	0/1	0/1	0/1
		II	5	0/1	0/1	0/1
		III	8	0/1	0/1	0/1
26-50	D	I	5	0/1	0/1	0/1
		II	8	0/1	0/1	1/2
		III	13	0/1	1/2	1/2
51-90	E	I	5	0/1	0/1	1/2
		II	13	0/1	1/2	1/2
		III	20	1/2	1/2	2/3
91-150	F	I	8	0/1	1/2	1/2
		II	20	1/2	1/2	2/3
		III	32	1/2	2/3	3/4
151-280	G	I	13	1/2	1/2	2/3
		II	32	1/2	2/3	3/4
		III	50	2/3	3/4	5/6
281-500	H	I	20	1/2	2/3	3/4
		II	50	2/3	3/4	5/6
		III	80	3/4	5/6	7/8
501-1200	J	I	32	2/3	3/4	5/6
		II	80	3/4	5/6	7/8
		III	125	5/6	7/8	10/11

Table 31: ISO 2859-1

Once all the necessary parts have been measured, it may be useful to record the data in tables to perform a statistical check using the "*variables method*" (measurements of a quantitative nature), for a hypothetical future production run.

PIECES

The parts that need to be measured are the ones we produced, so:

FRAME

Parameter selection with reference to the standard:

- batch: 140 pieces → Cod. F
- 32 samples
- presence of some tolerances → Lvl. 3
- AQL → 0,65

Tools and times:

- Micrometer for G7 tolerance → 20 sec.
- Go/no-go gauge for F7 tolerance → 5 sec.
- Caliper for hole positions → 15 sec.

PLATE

Parameter selection with reference to the standard:

- batch: 140 pieces → Cod. F
- 20 samples
- presence of some tolerances → Lvl. 2
- AQL → 2,5

Tools and times:

- 4 identical measurements with a caliper for hole positioning → 20 sec.
- Caliper for measurements related to the central hole → 15 sec.

FLANGE

Parameter selection with reference to the standard:

- batch: 280 pieces → Cod. G
- 8 samples
- presence of some tolerances → Lvl. 1 (because the piece is made of plastic, easily deformable and therefore easy to adjust and has relatively low cost)
- AQL → 2,5

Tools and times:

- Conical gauge for taper → 10 sec.
- Caliper for positioning 6 identical holes → 25 sec.

SHAFT

The threads are used for a grease fitting and a nut, so purchasing an M18 threaded ring gauge and an M10 go/no-go gauge would be an excessive expense given their function.

Since it is the central element of the wheel and has a tight diameter tolerance, we decided to measure the entire batch of 140 pieces.

Measuring the whole batch requires precise and fast instruments (such as go/no-go gauges); these are obviously expensive, but the cost will be amortized over the entire batch rather than a limited number of samples.

Instruments and times:

- Fork gauge 18 h6 → 5 sec.
- Length caliper → 15 sec.

COSTS

LABOR E MEASUREMENTS TIME

The labor cost of a worker, as previously noted, is 25€/h for the company.

For convenience we converted this to €/s, obtaining the following value: **6,94 * 10^{-3} €/s**.

By summing the times required for the various measurements on a single part, knowing the number of samples and the batch size, and taking into account the labor cost per operator, we can estimate the labor costs allocated to each piece:

FRAME

$€_{op1frame}$ = [(20 s + 5 s + 15 s) * 32 * 6,94 * 10^{-3} €/s] / 140 **= 0,063 €**

PLATE

$€_{op1plate}$ = [(20 s + 15 s) * 20 * 6,94 * 10^{-3} €/s] / 140 **= 0,035 €**

FLANGE

$€_{op1flange}$ = [(10 s + 25 s) * 8 * 6,94 * 10^{-3} €/s] / 280 **= 0,0069 €**

SHAFT

$$€_{op1shaft} = [(15\ s + 5\ s) * 140 * 6{,}94 * 10^{-3}\ €/s] / 140 = \mathbf{0{,}14\ €}$$

TOOLS AND COSTS PER PIECE

The tools needed to make all our measurements are five:

DECIMAL CALIPER

Figure 73: decimal caliper

We use it for: frame (140 pieces), plate (140 pieces), flange (280 pieces) e shaft (140 pieces), for a total of 700 pieces.

By amortizing equally, the cost for each piece is:

$€_{caliperperPiece} = 59{,}78\ € / 700 = \mathbf{0{,}085\ €}$

MICROMETER

Figure 74: micrometer

We use it only for the frame (140 pieces).

The cost for each piece is:

€$_{\text{micrometerperPiece}}$ = 280,88 € / 140 **= 2,01 €**

GO/NO-GO GAUGE Ø18 F7

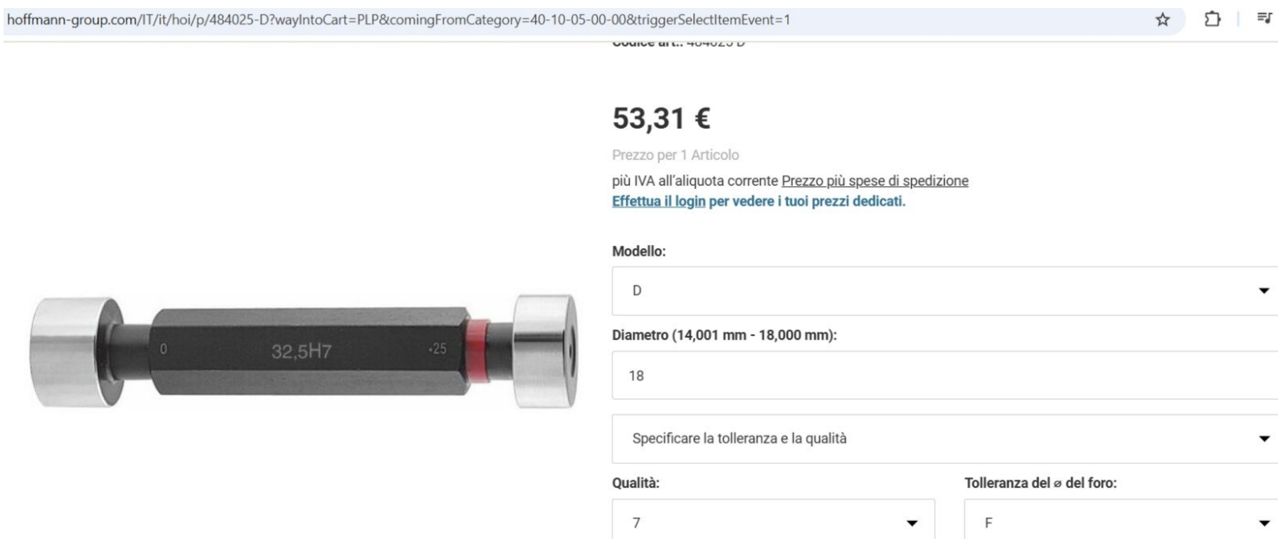


Figure 75: go/no-go gauge

We use it only for the frame (140 pieces)

The cost per piece is:

€$_{\text{gaugeperPiece}}$ = 53,31 € / 140 **= 0,38 €**

CONICAL GAUGE

Figure 76: conical gauge

We use it only for the flange (280 pieces).

The cost per piece is:

$€_{conicalgaugeperPiece}$ = 40,98 € / 280 **= 0,15 €**

GO/NO-GO FORK GAUGE Ø18 H6

Figure 77: go-no-go fork gauge

We use it only for the shaft (140 pieces).

The cost per piece is:

$€_{forkgaugeperPiece}$ = 232,26 € / 140 **= 1,66 €**

TOTAL FOR INDIVIDUAL PIECES

By adding up labor and tool costs, the metrology cost for each single piece amounts to:

FRAME

$$€_{metr1frame} = (0{,}063 + 0{,}085 + 2{,}01 + 0{,}38)\ € = \mathbf{2{,}54\ €}$$

PLATE

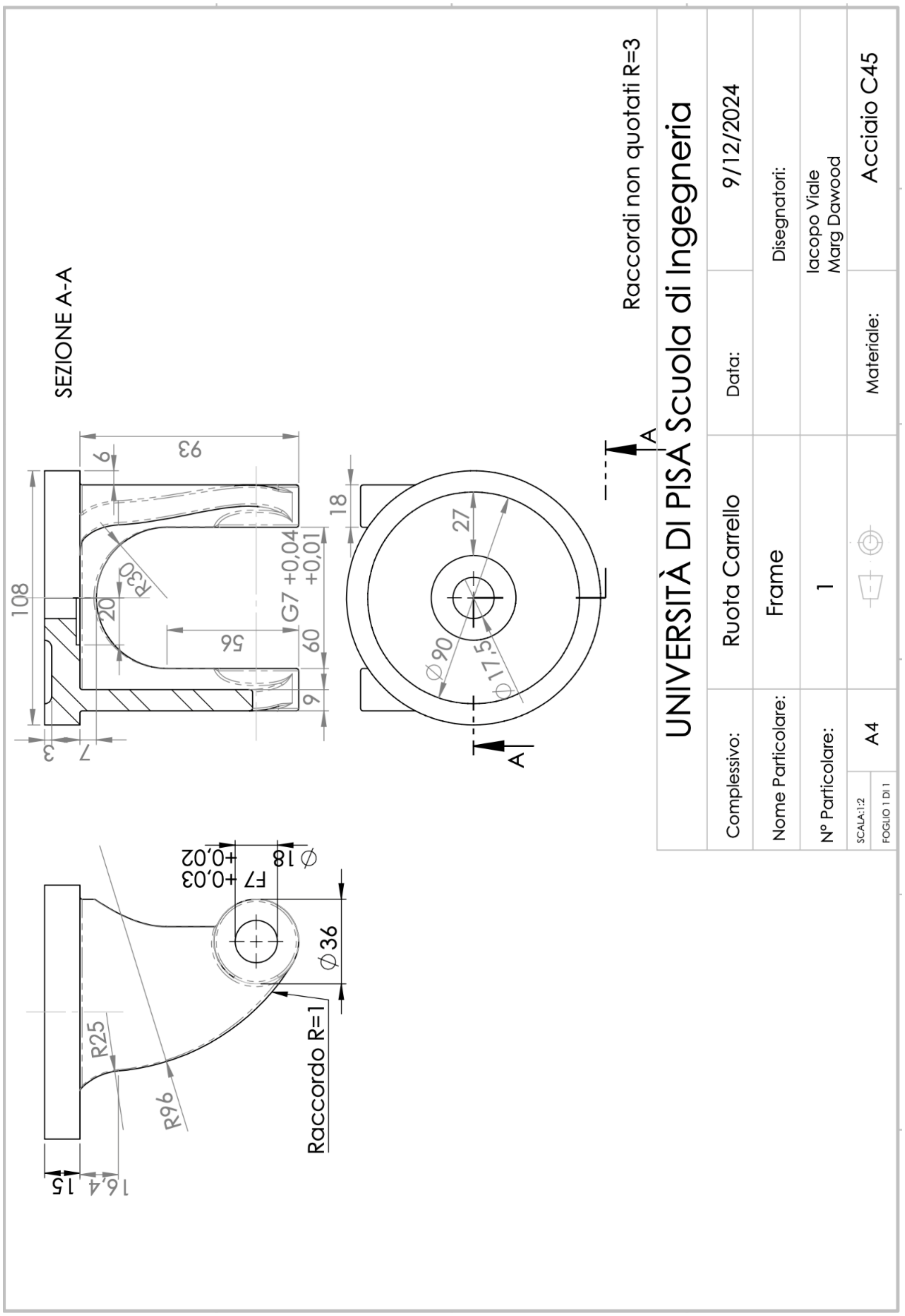
$$€_{metr1plate} = (0{,}035 + 0{,}085)\ € = \mathbf{0{,}12\ €}$$

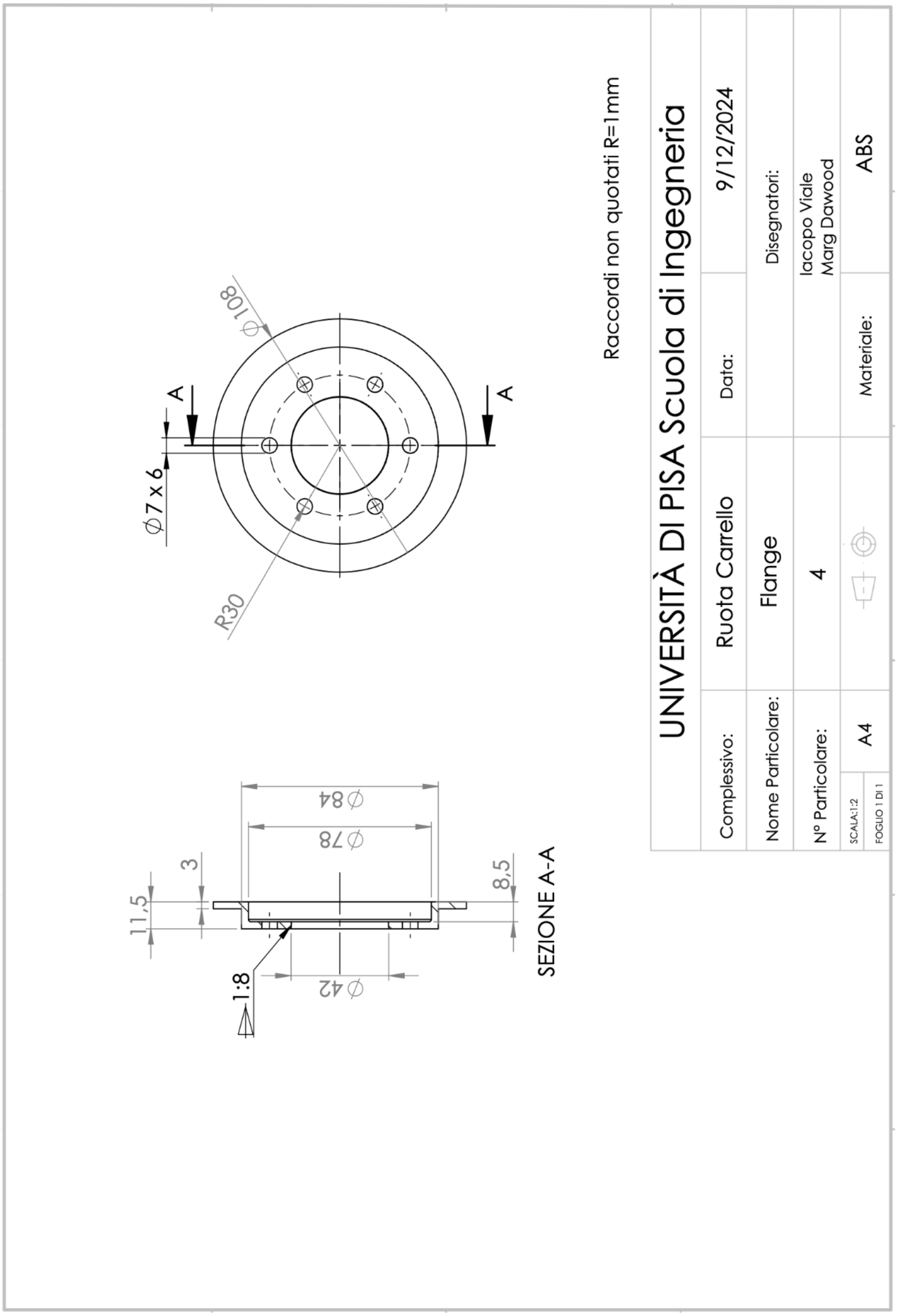
FLANGE

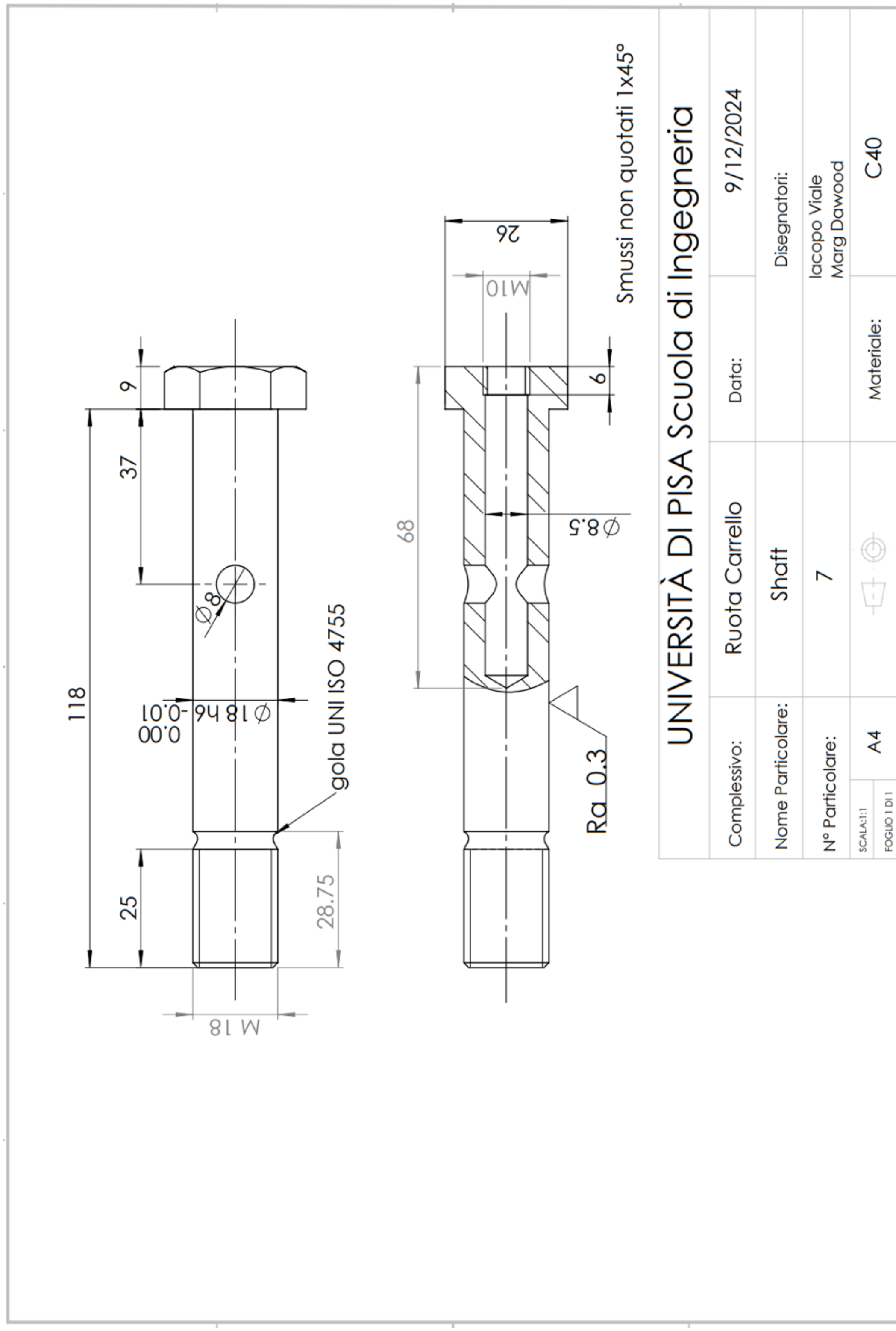
$$€_{metr1flange} = (0{,}0069 + 0{,}085 + 0{,}15)\ € = \mathbf{0{,}24\ €}$$

SHAFT

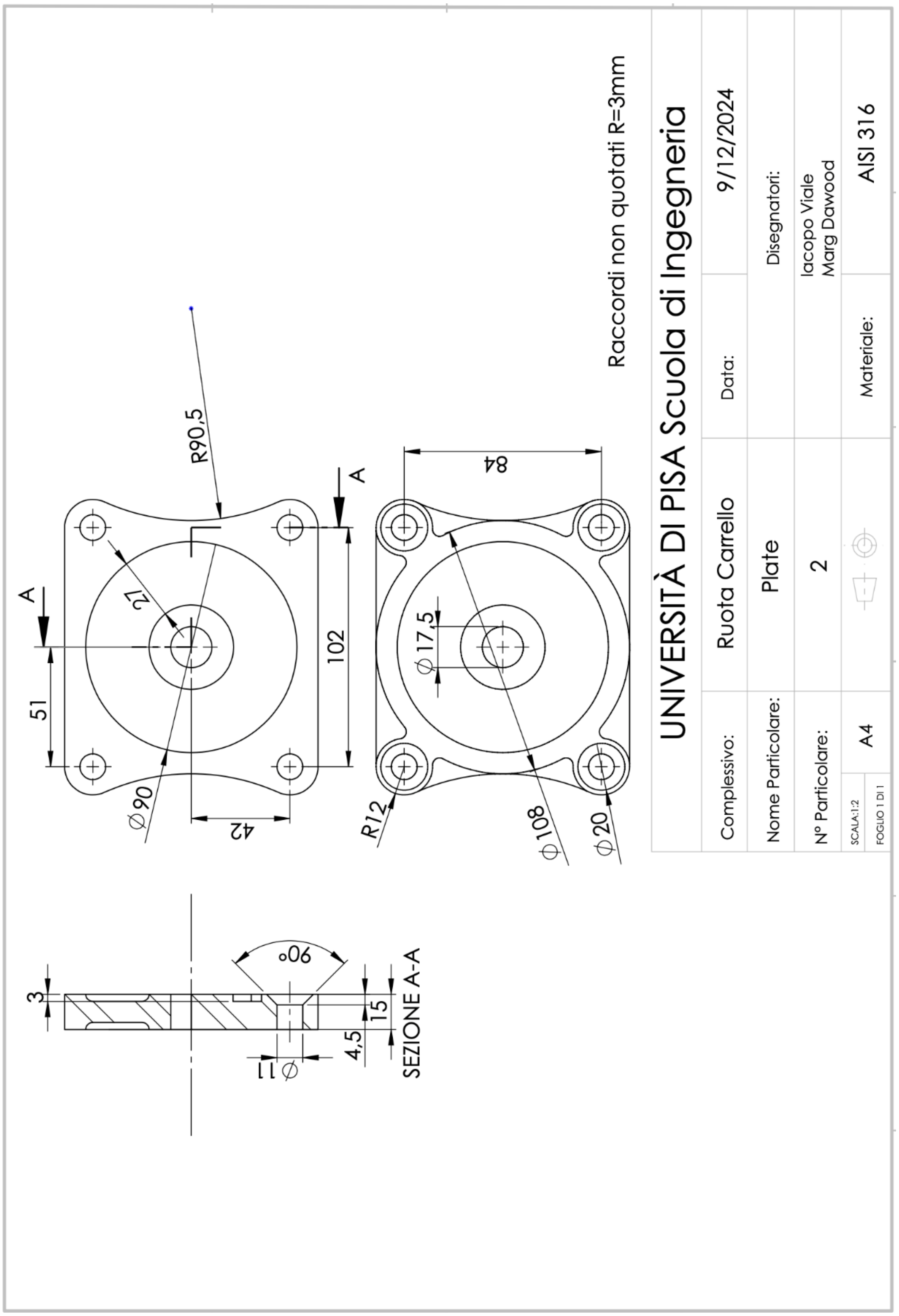
$$€_{metr1shaft} = (0{,}14 + 0{,}085 + 1{,}66)\ € = \mathbf{1{,}90\ €}$$


SEZIONE A-A
Raccordi non quotati R=3
Raccordo R=1
UNIVERSITÀ DI PISA Scuola di Ingegneria
Complessivo:
Ruota Carrello
Data:
9/12/2024
Nome Particolare:
Frame
Disegnatori:
Iacopo Viale
Marg Dawood
Nº Particolare:
1
A4
Materiale:
Acciaio C45
SCALA:1:2
FOGLIO 1 DI 1
108
93
56
60
20
R30
G7 +0,04
+0,01
18
27
⌀90
⌀17,5
⌀36
⌀18
F7 +0,03
+0,02
R25
R96
15
16,4
A


SEZIONE A-A
Raccordi non quotati R=1mm
UNIVERSITÀ DI PISA Scuola di Ingegneria
Complessivo:
Ruota Carrello
Data:
9/12/2024
Nome Particolare:
Flange
Disegnatori:
Iacopo Viale
Marg Dawood
Nº Particolare:
4
Materiale:
ABS
A4
SCALA:1:2
FOGLIO 1 DI 1



Smussi non quotati 1x45°
UNIVERSITÀ DI PISA Scuola di Ingegneria
Complessivo:
Ruota Carrello
Data:
9/12/2024
Nome Particolare:
Shaft
Disegnatori:
Iacopo Viale
Marg Dawood
N° Particolare:
7
Materiale:
C40
SCALA:1:1
FOGLIO 1 DI 1
A4
gola UNI ISO 4755
Ra 0.3
⌀18 h6 -0.01 0.00
⌀8
⌀8.5
M10
M 18
118
37
25
28.75
9
6
26
68


UNIVERSITÀ DI PISA Scuola di Ingegneria
Raccordi non quotati R=3mm
Complessivo:
Ruota Carrello
Data:
9/12/2024
Nome Particolare:
Plate
Disegnatori:
Iacopo Viale
Marg Dawood
Nº Particolare:
2
Materiale:
AISI 316
A4
SCALA:1:2
FOGLIO 1 DI 1
SEZIONE A-A
A
R90,5
27
51
102
42
⌀90
84
⌀17,5
R12
⌀108
⌀20
3
15
4,5
⌀11
90°

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