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GREEN-LOOP

Sustainable manufacture systems towards novel bio-based materials

WP5 – Wood composites material production

D5.3 - WC sample manufacturing by press moulding

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GREEN LOOP Consortium Partners

	Partner	Acronym	Country
1	IDENER RESEARCH & DEVELOPMENT	IDE	ES
2	NATIONAL INSTITUTE OF CHEMISTRY	NIC	SI
3	SLOVENIAN NATIONAL BUILDING AND CIVIL E. I.	ZAG	SI
4	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	FHF	DE
5	LABRENTA SRL	LBRT	IT
6	MIXCYCLING SRL	MYX	IT
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12	AUSTRIAN STANDARDS INTERNATIONAL	ASI	AT
13	INSTITUTO DE SOLDADURA E QUALIDADE	ISQ	PT
14	AXIA INNOVATION UG	AXIA	DE
15	ASOCIACIÓN DE INVESTIGACIÓN METALÚRGICA DEL NOROESTE	AIMEN	ES
16	NATIONAL COMPOSITE CENTER	NCC	UK
17	UNIVERSITY OF BRISTOL	UBRIS	UK

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Executive Summary

This deliverable outlines the work carried out to date to develop the design, formulation and manufacture of the components produced for the Greenloop wood composite value chain. In Deliverable 5.1 the technical requirements for the wood composite material were outlined and the use case identified. The use case would be manufacture of a bearing product using the wood composite material.

Materials for use within bearings require a low coefficient of friction and a low wear rate. The material to be used will be dictated by the demands placed on it during use. For high load or high temperature applications metals such as steel are required whereas for applications with lower demand polymer bearings are often used. These polymers are derived from fossil-fuels and so Greenloop work package 5 (WP5) aims to develop and demonstrate a more sustainable material to displace conventional fossil-fuel derived polymer bearings.

Tribological lab-based testing is being conducted to determine the best performing formulation. The results of this will be disseminated in Deliverable 5.6. However, to demonstrate the viability of the material beyond the lab, a bearing has been designed and will be manufactured as part of work package 6 (WP6). The bearing to be targeted will be a bearing within a conveyor roller system. This experiences regular loading as goods are passed along the conveyor system but not at such high loads that a metal bearing would be required. The bearing design is based on a commercially available bearing, currently made using a fossil-derived polymer. This will allow direct comparison between the current market offering and the Greenloop developed bearing. Demonstration of the bearing at Labrenta's manufacturing site will be carried out in WP6.

A design of experiments has been carried out to identify the best material formulations. There are three main components that have been varied in the composition. Firstly a biopolymer is used as the matrix material which binds the composite together and acts as the contact surface for the bearing. Within the polymer are additional fillers to enhance its tribological properties, these are short wood fibres and inorganic fillers. The ratios of components are 40-80 wt% biopolymers, 20-30 wt% wood fibers, and 20-30 wt% inorganic fillers. Primary testing criteria have been:

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- i. Tribology - Coefficient of friction
- ii. Tribology - Material wear coefficient
- iii. Mechanical - Compressive strength

The formulations have sufficient compressive strength to withstand the chosen use case and the best performing materials have exceeded the tribological performance on existing benchmark materials. Full testing results will be disseminated in Deliverable 5.4 and Deliverable 5.6.

The feedstocks were compounded using an Eirich mixer initially, followed by an extrusion process to ensure homogenisation. Once compounded the material was pelletised ready for further processing. Compression moulding was then employed to shape the material into its required geometry. Initially this was into flat panels from which cylindrical rings can be machined for tribological testing. In WP6, manufacture of the final conveyor roller bearing will begin. Described within this report is the tooling design and commissioning required to facilitate this manufacture. A flexible tooling design has been produced to enable modification to the manufactured part geometry if required.

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Abbreviations

TRL	Technology readiness level
NDT	Non-destructive testing
WP5	Work package 5
WP6	Work package 6

1 Manufacturing process overview

Greenloop work package 5 (WP5) aims to develop a wood composite material for use in bearing applications. The development has encapsulated material formulation, manufacturing optimisation and characterisation of the final material. By the end of WP5 the target is to reach technology readiness level 5 (TRL 5). The key characteristics for a material to be used as in a bearing application are high compressive strength, a low coefficient of friction and low wear.

This report outlines the work to date on the bearing design, formulation trials and manufacturing. Further deliverables will outline the full material characterisation results (Deliverable 5.4) and the tribological evaluation (Deliverable 5.6).

1.1 Manufacturing overview

The largest component by mass within the formulation is a bio-derived thermoplastic polymer which is filled with a lignin (wood) powder. The commercial product Arboblend supplied by Tecnaro is used as the matrix for the composite material formulation. Arboblend is a biopolymer-lignin mixture and, depending on the formulation, Arboblend consists of various biopolymers such as polylactide, polyhydroxybutyrate, starch, cellulose, green PE, bio-PA, lignin, natural resins, natural fatty acids, waxes, and/or additives.

To modify the properties of this polymer wood powder and inorganic fillers have been incorporated. Figure 1 shows the basic steps which are required to process the raw materials into the final part. The compounding process has been carried out within an Eirich mixer and a single screw extruder, details of this are outlined in Section 3. Once compounded the material is melted and shaped by compression moulding as detailed in Section 4. The compression moulded part is then machined into the geometry required for the final component. Section 2 details the design process for the final component.

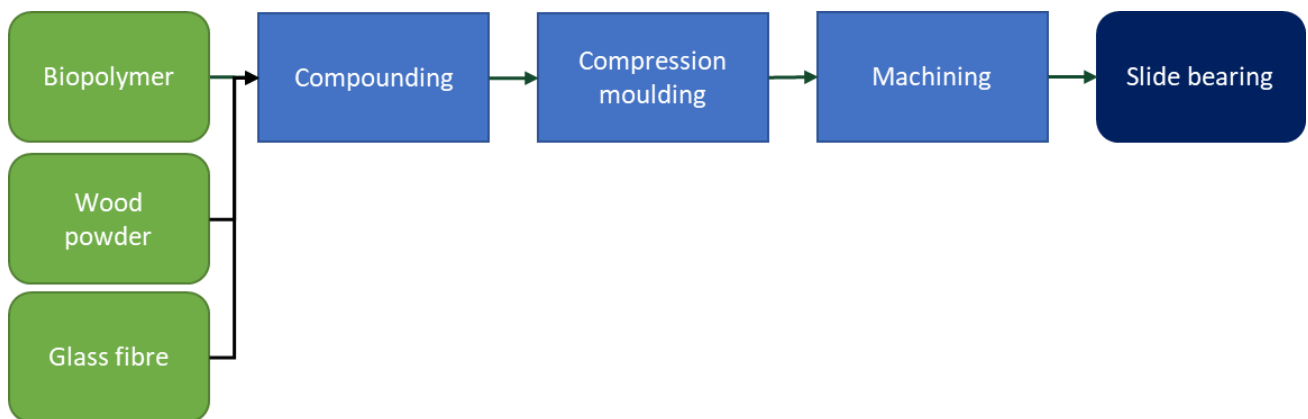


Figure 1: Process flow for wood composite value chain manufacturing.

2 Bearing design process

Deliverable 5.1 defined the use case to be targeted for the wood composite value chain. Bearing applications were identified as a promising use for wood composite materials to replace bearings that are currently made from less sustainable sources (metals, fossil-derived polymers). To demonstrate these bearing in an industrial setting Labrenta (LBRT) will incorporate the bearing within one of their pieces of equipment.

2.1 Injection moulding component

The initial target was a slide bearing within an injection moulding machine in use at LBRT. The bearing, shown in Figure 2, aids the moving of the platen during the thermoplastic processing.



Figure 2: Slide bearing with a LBRT injection moulding machine.

A baseline calculation was carried out using the equipment dimensions provided by LBRT to assess the feasibility of replacing this component with a wood composite material.

The platen mass supported by the bearings was 600 Kg and there are four contact points. Assuming an equal loading each bearing would be supporting 150 Kg, roughly 1500 N. The existing contact area for each bearing is 2.5 mm² therefore a pressure of 600 Nmm⁻² is applied on each bearing. This is a much higher pressure than is suitable for thermoplastics and testing on the initial wood composite formulations indicated that this far exceeds the compressive strength of the material. The best performing initial wood composite formulations did not exceed 100 Nmm⁻².

Therefore to make the injection moulding slide bearing viable, the contact patch would need to be significantly larger to generate an acceptable applied pressure. The constraints of the equipment meant that the maximum bearing contact area was 6.25 mm². If this were the case the pressure on each bearing would still be too high at 240 Nmm². This calculation also assumed a generous contact strip width of 0,25mm, whereas for the current metallic bearing it is likely ~0,05mm or less. It was concluded that the applied loads onto the bearing material from the platen will exceed the compressive strength of the wood composite material. To avoid the potential for material failure in this dry bearing an alternative product solution was sought.

As outlined in Deliverable 5.1 Section 3.2, if the injection moulding bearing was not suitable then another industrially relevant application should be sought. Plastic bearings, typically using fossil-fuel derived polymers, are used across a vast range of industrial equipment. The global market was estimated to be worth \$617.42

million in 2021 [1]. As they are typically used for lower load cases compared to metal bearings, replacement of a plastic bearing with the wood composite material was targeted.

2.2 Conveyor roller bearing

A new application was selected to be included in a different piece of equipment at LBRT. This was a bearing for a conveyor roller support system used at LBRT's manufacturing site to transport loaded boxes of components. The conveyor roller is shown at the LBRT manufacturing site in Figure 3.



Figure 3: Conveyor roller in situ at LBRT.

Within each of these rollers is a plastic bearing at each end. The bearing is a dry bearing (non-lubricated) which is seated within the roller and rotates around a fixed steel pin in the framework of the conveyor system. A schematic of the setup is shown in Figure 4. The steel pin at each end holds the bearings in place, allowing the roller to freely rotate. This project will produce wood-composite bearings to replace those currently used within the conveyor rollers at LBRT. To demonstrate their use the wood composite bearings will be housed within a new roller before being fitted on to the LBRT conveyor roller frame. The new roller will be a metal roller (likely aluminium) which will be purchased for use within the project.

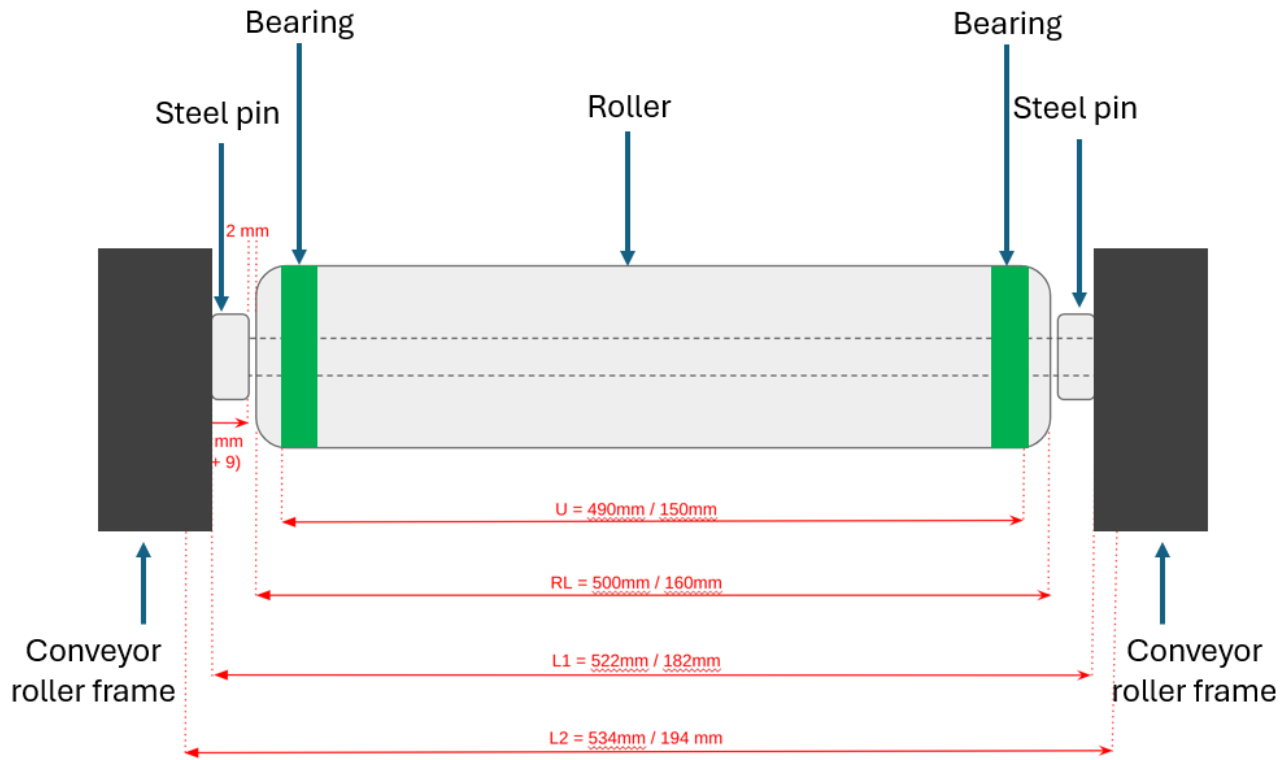


Figure 4: Schematic of roller into which the wood composite bearing will be incorporated.

This bearing solution will be initially manufactured from a cylindrical moulding which is a simple oversize blank (Figure 5), then machined to shape and size to fit into the new conveyor roller tube.

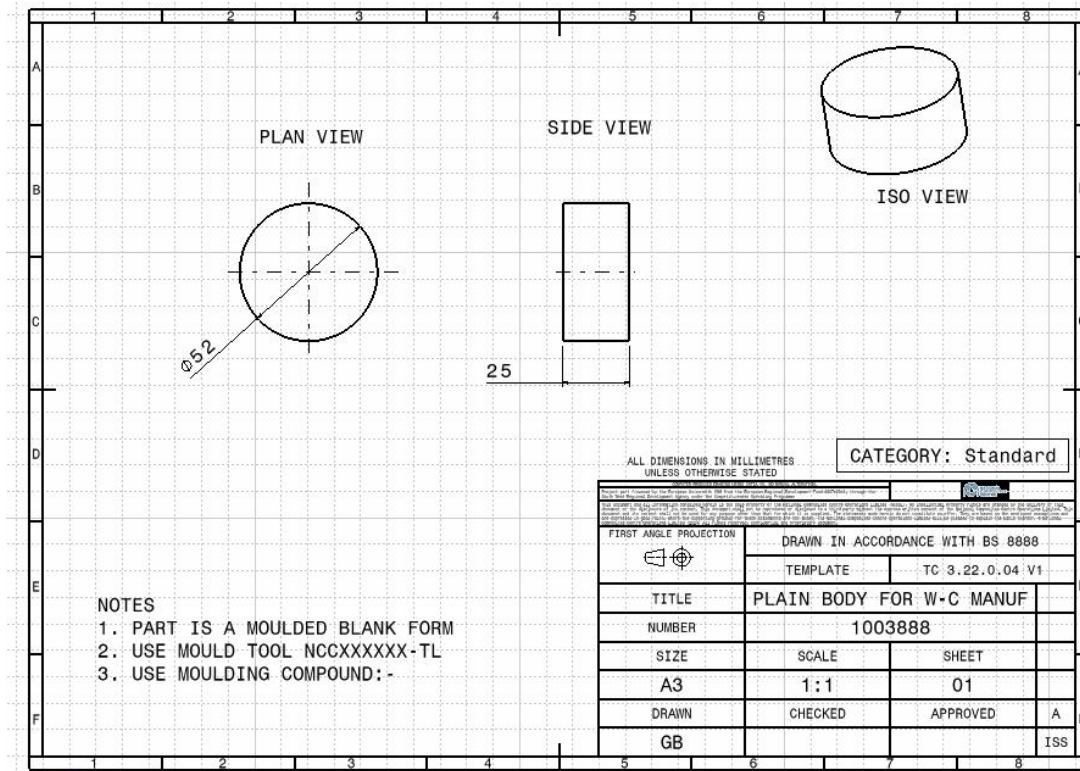


Figure 5: Wood composite blank from which the final component will be machined.

The final shape is shown in Figure 6. The retention within the roller will be achieved initially by 'O' rings seated in a machined groove. The bearing contact surface is a machined hole in the wood composite material. The surface roughness condition is still to be determined after trials to machine the parts are completed. Longer-term, the ambition will be to mould the part with the necessary features included, as this will provide a part with a lower surface roughness which may improve the tribological performance. The bearing design has been chosen to mimic a current bearing which is commercially available. This will enable a performance comparison between the existing bearing, made from fossil-derived polymer, and the Greenloop wood composite bearing.

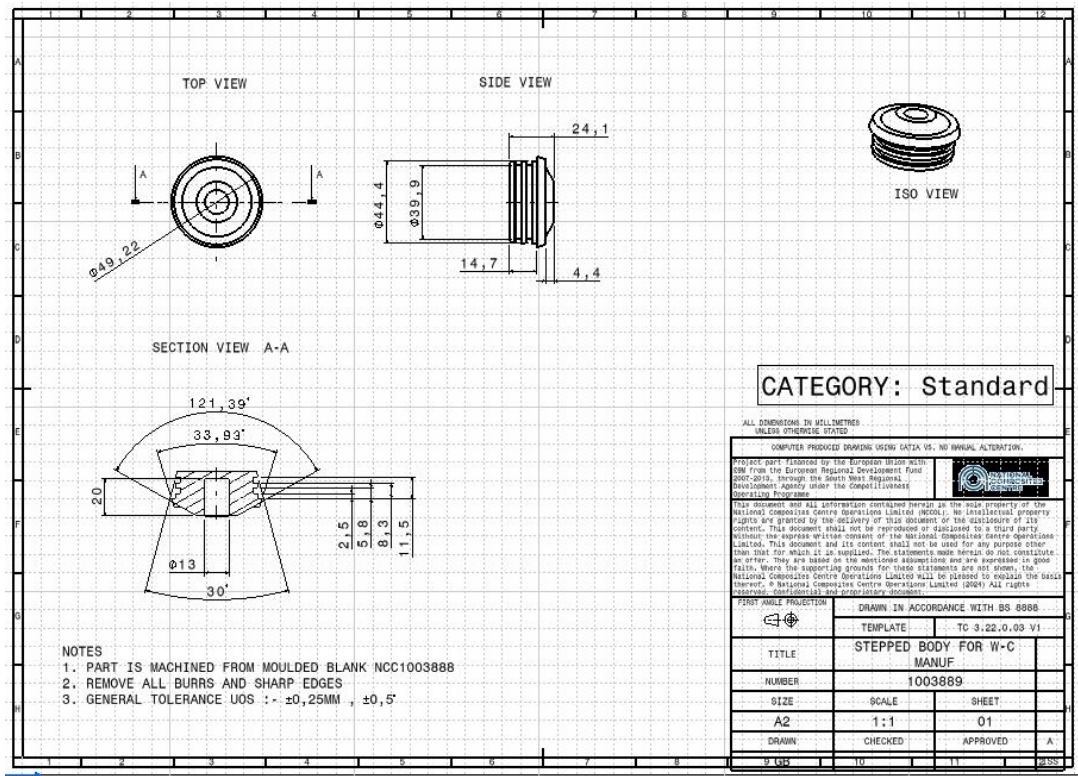


Figure 6: Final bearing geometry.

The conveyor rollers use a polymer, injection moulded end cap and a metal conveyor roller, this material choice creates a restriction of load capability of the conveyor system, it is intended for lightweight load movement only. The conveyor system selected has a load rating of 25-35kg. A load rating of 30 kg, spread across two bearings, and with a contact area of 2 mm² would apply 75 Nmm² of pressure to each bearing. This is below the compressive strength of the wood composite materials being developed.

The above calculation shows that the conveyor roller bearing proposal has a much lower applied contact load onto the bearing pin, which gives optimism for a use case which is going to be durable and able to withstand the operating conditions. The material wear rate is being evaluated at FHF and will be reported in Deliverable 5.6.

The final aspect of the design process will be to determine a cost model for manufacture of a bearing. However this can only be completed after there is a good understanding of durability of the material being used and the rate of production. This will feed into the business case assessment being carried out in WP7.

3 Wood composite compounding

The process of composite manufacturing for tribological applications, particularly for use as a sliding material, includes the steps of mixing, extruding, and shaping. The goal is to achieve a material using a biopolymer as a binder and wood as a filler, which attains friction and sliding values that exceed the current state of the art.

The starting materials used include a polymer matrix based on a biopolymer, wood flour or wood fibres, and non-reactive fillers. All components are in dry form with low water content. Thermoplastic polymers, which soften and melt at relatively low temperatures, are preferred when selecting the binders, as they possess some unique properties like reversibility, adhesion, processability, mechanical properties, chemical resistance, cost-effectiveness and customisation. Additionally, the use of thermoplastics should enable reuse in the process, although this will need to be demonstrated in WP6. Wood flour or wood fibres are cost-effective fillers that can be easily processed with polymer binders due to their chemical functionality.

Generally, inorganic substances in particulate form, such as graphite, molybdenum disilicide, layer silicates, or boron nitride, are suitable as fillers. These substances act as lubricants due to their 2D layer structure (see Figure 7) but also as fillers that contribute to improved strength. Short inorganic fibres from a few micrometres to approximately 10 mm made of glass or basalt can be added. These are thermally stable and can be processed by extrusion.

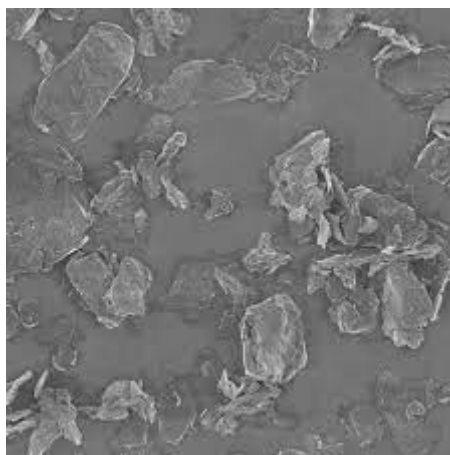


Figure 7: SEM image of TIMREX® KS 15 (IMERYS GRAPHITE & CARBON)

The commercial product Arboblend from the company Tecnar is used as the basis for the composite material production. Arboblend is a biopolymer-lignin mixture, contains renewable raw materials, and is approved for food contact. Depending on the formulation, Arboblend consists of various biopolymers such as polylactide, polyhydroxybutyrate, starch, cellulose, green PE, bio-PA, lignin, natural resins, natural fatty acids, waxes, and/or additives.

For the starting mixtures, the individual component proportions were as follows: 40-80 wt% biopolymers, 20-30 wt% wood fibers, and 10-30 wt% fillers (in form of glass fibre).

Due to the different properties of the components, mixing must be carried out in a specific sequence and with precisely set parameters. First, the polymer is introduced. Then, the wood components are added. Finally, additional fillers are added. This has the advantage that the wood particles are pre-impregnated with the biopolymer before the additional fillers are added. For this first stage of mixing an Eirich mixer (Type R02E) was used with a special attention to the temperature input on the mixing components. The aim was to find

the best temperature processing window which allows for the polymer to soften and incorporate some of the wood fibres but not to allow degradation of the biopolymer or wood.

After compounding in the Eirich mixer the material was pass through a single screw extruder. The extruder used in this work is shown in Figure 8. During extrusion, the mixture is fed into a funnel-shaped feeder, and the material is moved through the barrel by a conveying or plasticizing screw (conveying zone). The screw was heated to temperatures between 180 and 200 °C. The rotational speeds ranged from 20 to 60 revolutions per minute and together with the screw diameter (15mm) this determines the rate of material throughput. At the end of the extruder barrel, the thoroughly mixed, still molten mass was forced through a die with a round cross-section with a diameter of 1 mm to 3 cm. The continuous strand of material was then optionally cooled by passing it through a water bath. At the end of the cooling section, the strand was cut by a mechanical cutting device. As a result, material produced was in the form of pellets or granulated material in sizes ranging from 3 to 8 mm. The extruded pellets can then be used in a subsequent manufacturing step to form the desired part geometry.



Figure 8: Extruder used in the process of biopolymer/wood fibres formulation.

The shape forming can be used to produce simple geometries such as plates or flat panels. Corresponding components with tight tolerances can be then obtained from these basic shapes through mechanical finishing processes such as milling, grinding, drilling, or turning. More complex geometries in final contours are also possible if suitable tool cavities are available, into which the mixture in the form of pellets or granulates is introduced. Common processing methods for pellets include compression moulding. and injection moulding. For quality control purposes and to allow basic testing 100 x 100 mm test panels were produced by compression moulding. More detail is included in the following section.

Quality was assessed by X-ray (CT) and density measurements to ensure homogeneity of plates and consistency of the density. The size of the test plates was 100 x 100 x 4.5 mm. Typical CT results are shown in Figure 9. Three test specimens were made using three different glass fibre fillers concentration. Optical viewing of the samples gives little information of how good the fillers are incorporated in the matrix. The CT measurements show us that the fillers, here appearing as white intrusions, are homogenously distributed around the matrix as shown by the CT pictures. During the CT measurement all the volume of the sample is analysed and for clarity only one picture per sample is shown in Figure 9.

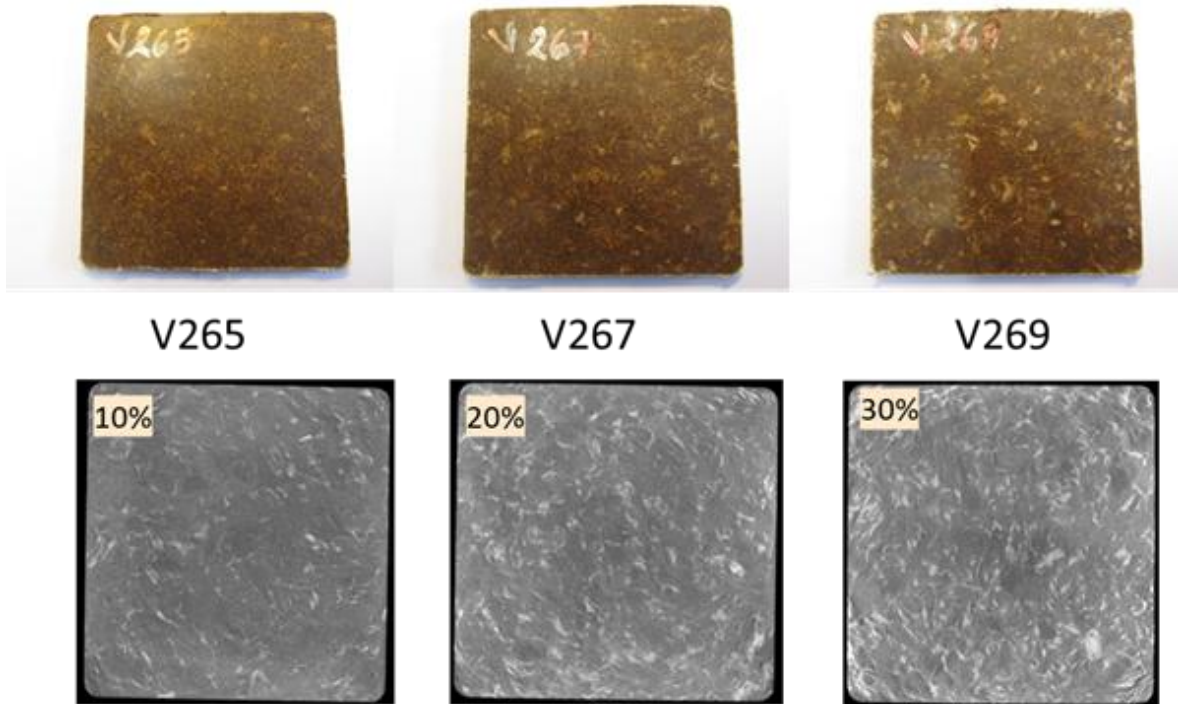


Figure 9: Top, Optical images of test plates. Bottom, CT scans of test plates.

4 Wood composite compression moulding

Once compounded, the material must be shaped into its final form. This is done by compression moulding; melting the material within a heated tool and applying pressure to force the material into the desired geometry.

4.1 Test components

Initial work was carried out on a simple geometry part, a flat panel, to understand the optimised processing parameters for the material.

The processing conditions are described below:

- Press model = Bipel 500 kN Laboratory press
- Temperature = 180 °C
- Part width = 200mm
- Part length = 200 mm
- Part thickness = 3-10 mm
- Dwell time = 10 mins

Figure 10 shows a typical part produced. The surface finish was good, and no voids or surface defects were observed on visual inspection. Further inspection is ongoing to assess the porosity of the panel using non-destructive testing (NDT).



Figure 10: Compression moulded wood composite panel.

From the flat panels, components will be machined to a geometry defined within standard DIN 1850-6 [2]. The geometry is shown in Figure 11. These components will be used for tribological testing at FHF.

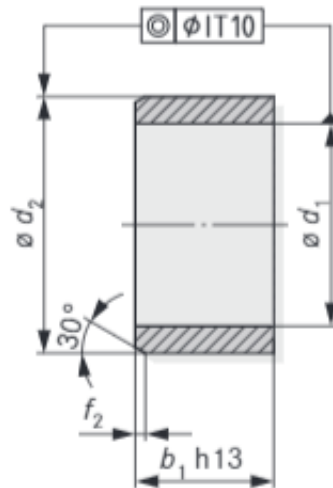


Figure 11: Test coupon geometry defined in DIN 1850-6. $d_1 = 10$ mm, $d_2 = 16$ mm, $b_1 = 10$ mm, $f_2 = < 0.5$ mm.

4.2 Final components

To produce the final conveyor roller bearing components as outlined in Section 2 a manufacturing plan was put together to produce oversized polymer blanks from which the final component could be machined out. The top-level process is shown in Figure 12. Produce oversized blanks enables flexibility during the part optimisation work as the final geometry can be easily modified if required based on the testing results. These parts will be manufactured as part of work package 6 to demonstrate scale of production of a real-life part.

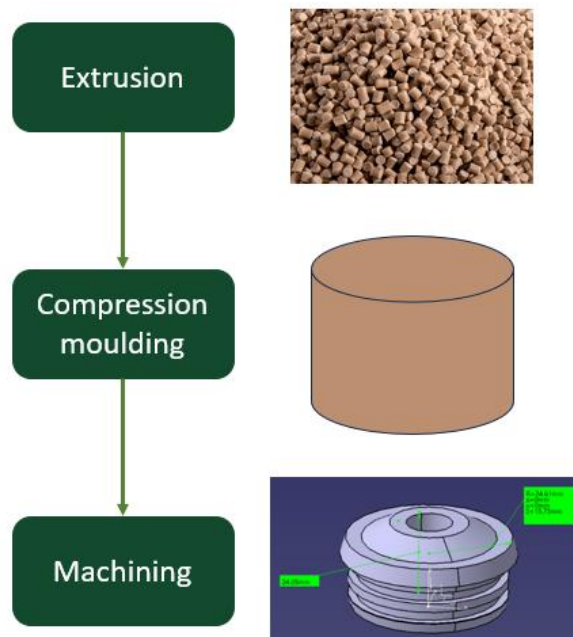


Figure 12: Steps required to process compounded pellets into the bearing component.

4.2.1 Compression mould tooling

Crucial to successful manufacturing during compression moulding is the design of the tooling. This is the mould which is inserted into the press and dictates the shape of the final component.

The mould tool is composed of:

- Bolsters (Figure 13a): Body of the tool and typically made of steel. They may have directly machined cavities into which the polymer is loaded or alternatively they can accommodate interchangeable inserts that contain the polymer cavity. In this case the tool has been designed with removal inserts to increase the flexibility of the tool.
- Base Plate (Figure 13b): Serves as the interface between the tool and press machine.
- Pillars and Bushes (Figure 13c): There are four sets in this tool, guiding the top and bottom halves for precise mould closure.
- Cavity Inserts (Figure 13d): Interchangeable parts that dictate the moulded shape.
- Insulation Boards: Provide thermal insulation to maintain the correct mould temperature and minimise the energy input required to keep the mould at temperature.
- Transit Straps: Secure the mould halves together during transportation to prevent damage.
- Pressure Pads: Ensure uniform pressure and maintain the required levelling gap between top and bottom halves.

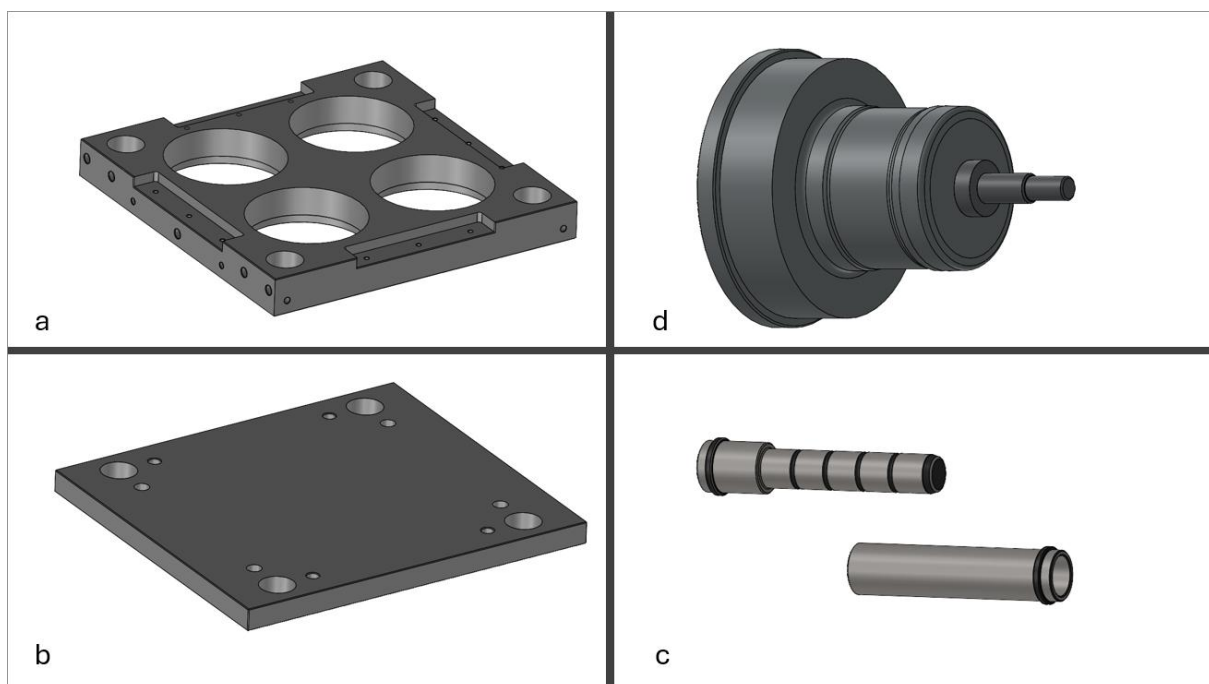


Figure 13: (a) Bolster; (b) Base Plate; (c) Pillars and Bushes; (d) Insert.

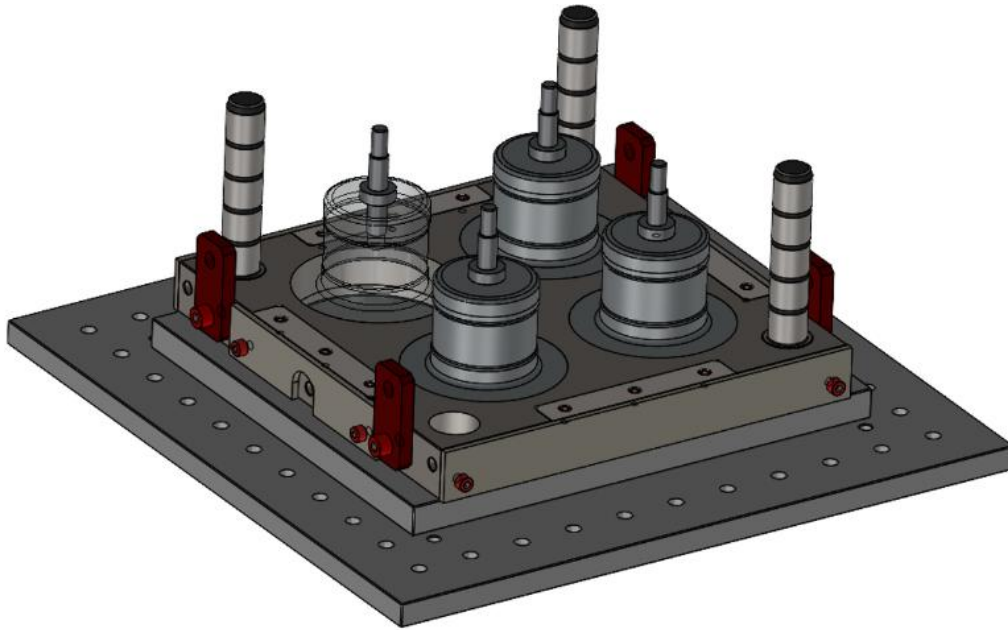


Figure 14: Top half of the tool, with transit straps in red and insulation boards surrounding the bolster plate.

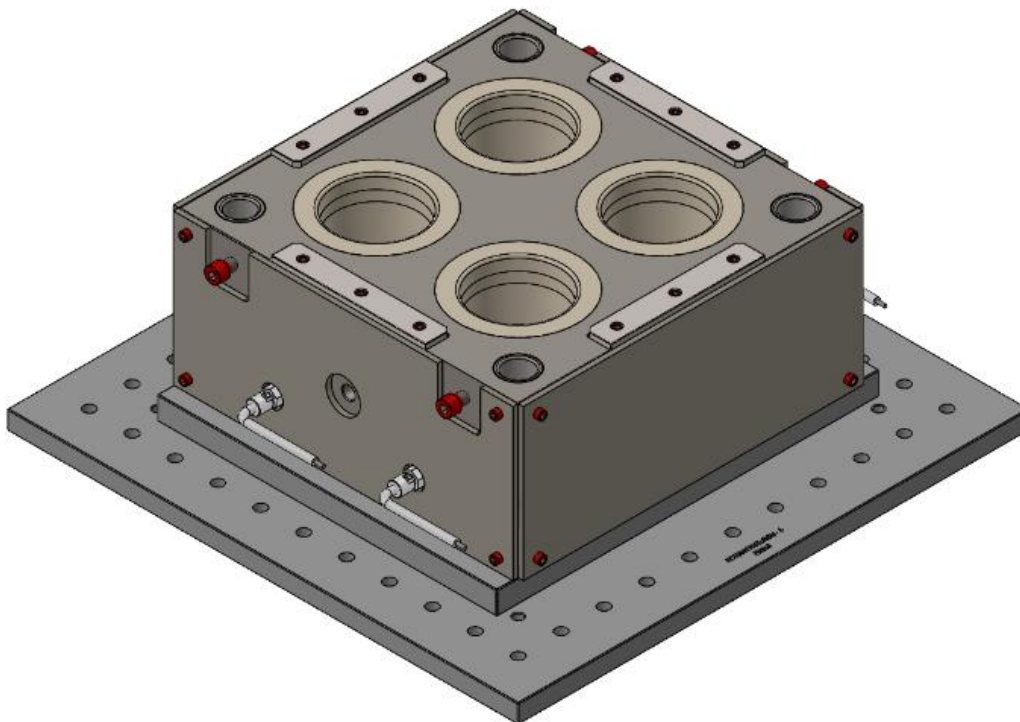


Figure 15: Bottom half of the tool, with thermocouples bolted into the bolster plate.

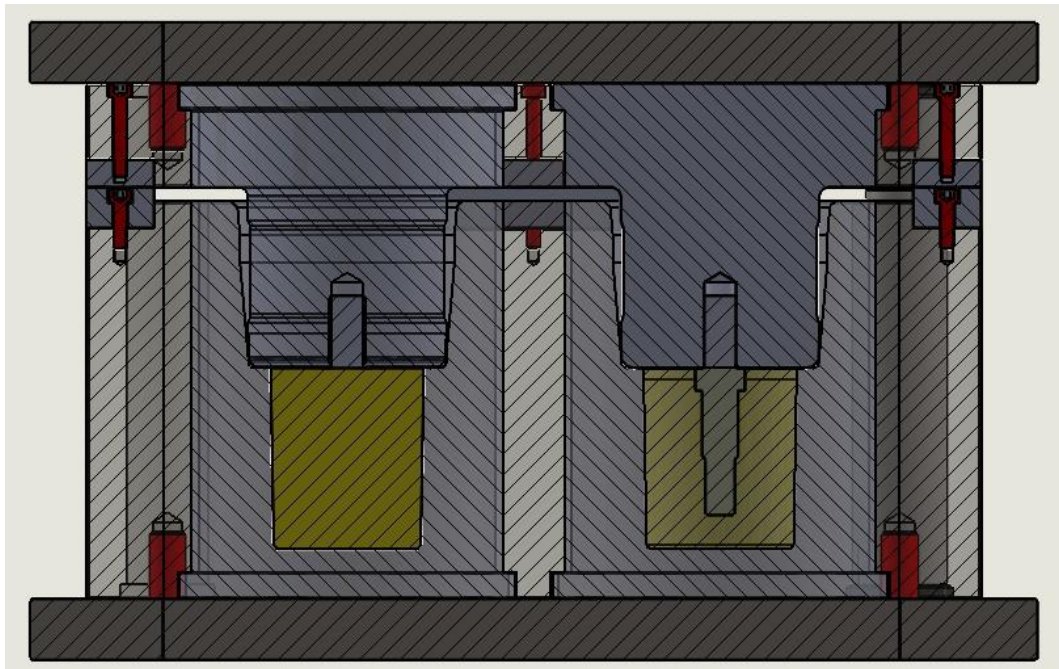
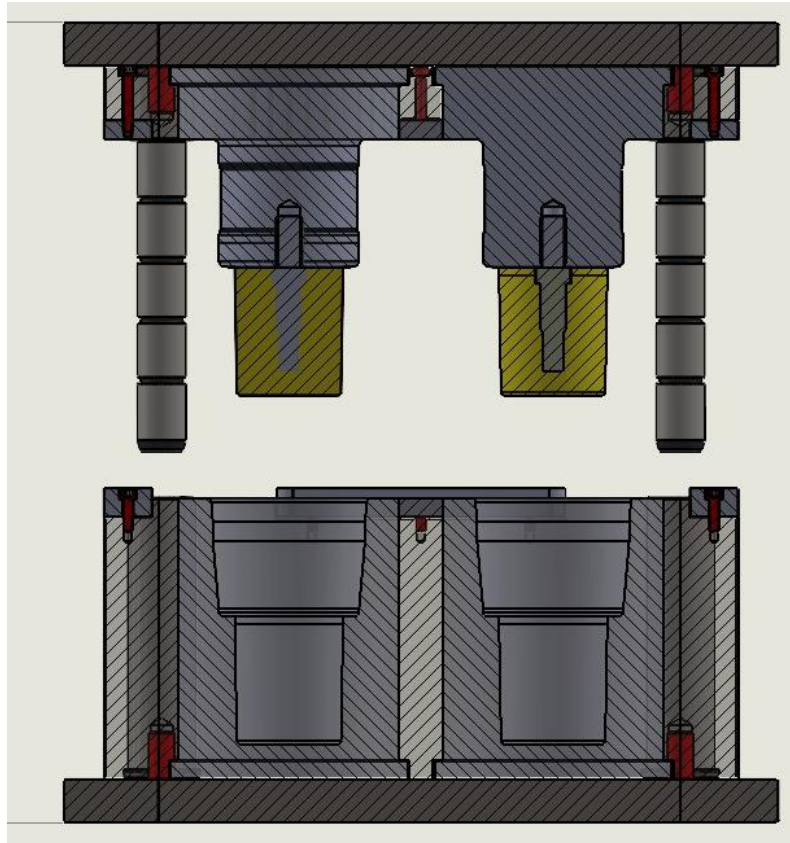


Figure 16: Top – Alignment of the top and bottom tooling halves when open. Bottom - Alignment of the top and bottom tooling halves when closed.

in the tool cavity, gaps between the pellets mean the raw material volume is larger than the moulded part. On top of this it is standard practise in the polymer industry to add +10% extra raw material to ensure the part volume is covered. The powder chamber (Figure 18) sits above the mould cavity and accommodates the extra volume of the pellets prior to compression moulding.

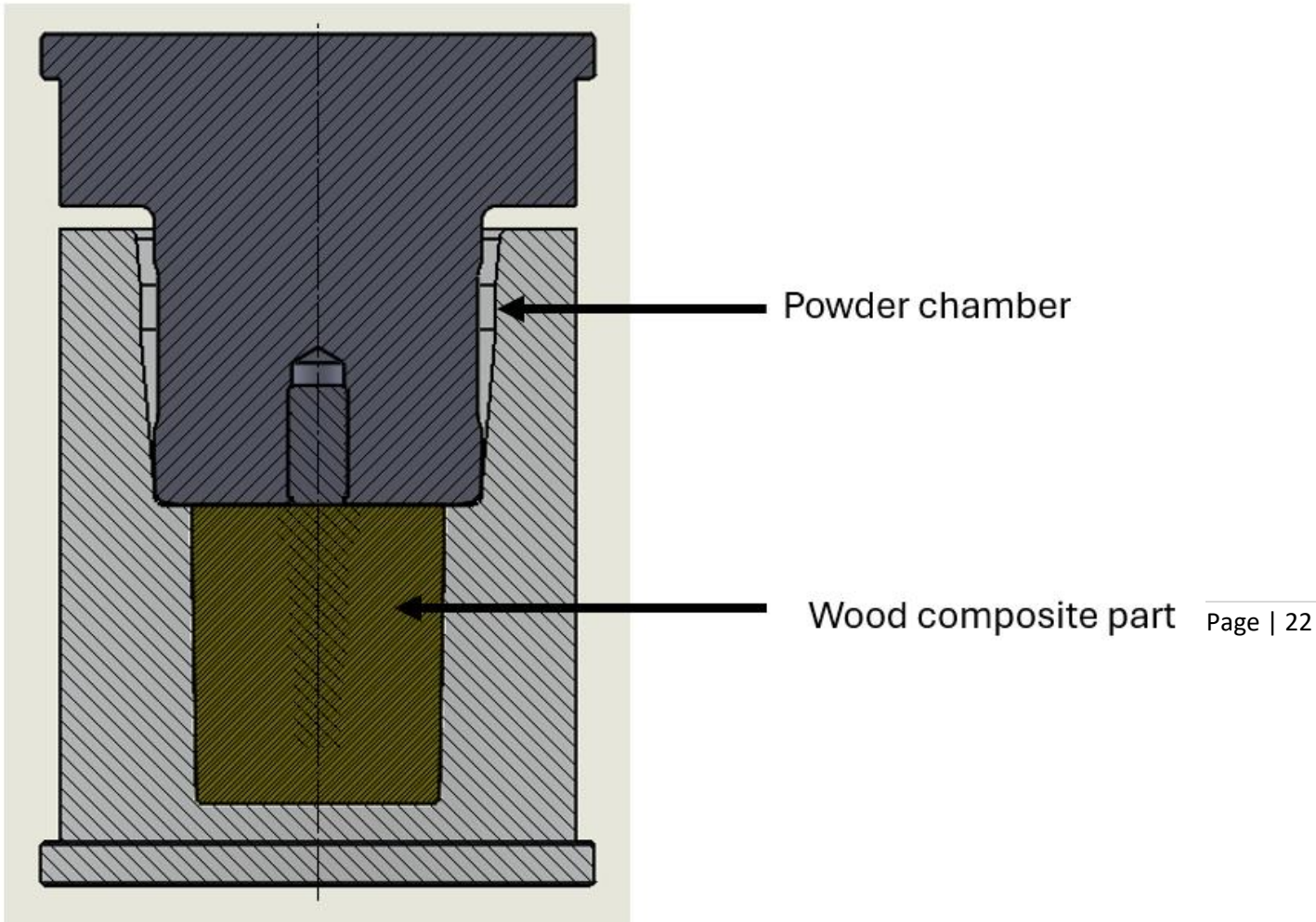


Figure 18: Schematic of powder chamber and component chamber.

Component extraction

Once the compression moulding cycle is complete, the moulded part must be extracted. The tool includes a threaded insert to pull the part out automatically as the tool is opened, shown in Figure 19. The insert will be used to support the part in a lathe during the final machining.

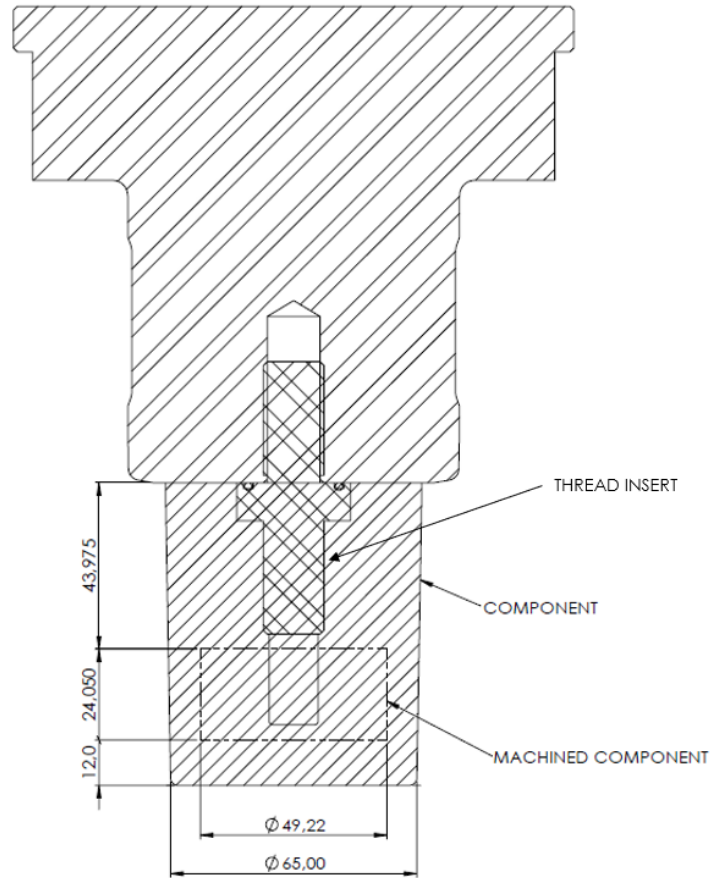


Figure 19: Moulded part attached to threaded insert in the upper half of the tool.

Interchangeable mould inserts

Interchangeable mould inserts have been incorporated into the tool design to allow quick changes in product shape, while using the same basic tool assembly. This will increase the flexibility to modify the part geometry if required. It also benefits the tooling manufacture as it is easier to apply heat treatment and surface finishes to smaller, individual inserts.

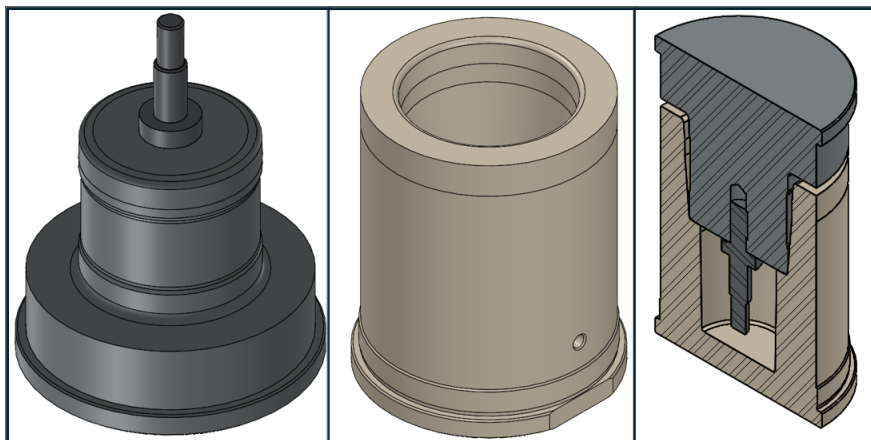


Figure 20: figure (a) Top insert; figure (b) Bottom insert; figure (c) Top and Bottom inserts assembled.

Materials

Steel is commonly used in mass production compression moulding tools. The bolsters are made of steel grade 1.1730, commercially known as Mild Steel. H-13 has been selected for producing cavity inserts. These were hardened and tempered to 48-52HRC to enhance wear resistance. Additionally, to improve material flow and facilitate component extraction the cavities have been polished to a mirror finish. The pressure pads are made of ground flat stock (GFS) and hardened and tempered to 48-50HRC. Mould standard components, such as, pillars, bushes and thermocouple were acquired from Meusburger. The remaining standard components can be purchased from a wide range of commercial suppliers.

4.2.3 Manufacturing

The manufacturing of the final parts will use the tooling outlined above. The processing parameters are still to be defined but the initial parameters will be based on the learning from the test part manufacturing.

The tool is designed to be used in the NCC's Hare Press, and its primary specifications are:

- Platen size: 0.6m x 0.6m
- Maximum ram stroke: 0.5m
- Max pressure: 1000 kN
- Max top half tool mass: 500kg
- Maximum platen temperature: 400 °C
- Minimum break open force: 200 kN

This manufacturing will be carried out in work package 6 and will be reported in Deliverable 6.4.

5 Concluding remarks

To develop the wood composite value chain a development programme has been carried out to produce a material with sufficient tribological properties for use in a bearing application. The initial work to identify a use case for this material settled on its use as a bearing within a conveyor roller system. This considered the properties of the initial formulations produced in Task 5.2 and the requirements of the project end user Labrenta. The final design is based on a commercially available bearing, currently made using a fossil-derived polymer. This will allow direct comparison between the current market offering and the Greenloop developed bearing.

The material formulation uses a lignin-filled biopolymer as the matrix material and incorporates wood and inorganic fillers to improve the tribological properties of the composite. The ratios of components are as follows: 40-80 wt% biopolymers, 20-30 wt% wood fibers, and 20-30 wt% inorganic fillers. The fillers act as lubricants within the material's structure to reduce the coefficient of friction and contribute to an improved strength of the polymer composite. To produce the composite the feedstocks were first combined using an Eirich mixer followed by extrusion and pelletisation.

Compression moulding trials have been carried out to shape the material into panels. From this a cylindrical ring test pieces can be machined according to the geometry required in DIN 1850-6:1998. These test pieces will be used to further characterise the tribological properties of the material. The results of this will be disseminated in Deliverable 5.6.

Preparation for manufacturing of the final conveyor roller bearing has been carried out. The parameters used in the flat panel compression moulding will be used to optimise the final part manufacturing. The bulk of the preparation work has been on the tooling design and commissioning its manufacture. A robust, flexible tooling construction has been designed to enable agile manufacturing. This will allow demonstration of production to be carried out in WP6 as the value chain is taken up to TRL 6.

6 References

- [1] Business Research Insights, "PLASTIC BEARING MARKET REPORT OVERVIEW," [Online]. Available: <https://www.businessresearchinsights.com/market-reports/plastic-bearing-market-103235>. [Accessed 30 07 2024].
- [2] DIN, *DIN 1850-6:1998*, 1998.