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GREEN-LOOP

Sustainable manufacture systems towards novel bio-based materials

WP5 – Wood composites material production

D5.1 – Wood composites specifications

Document information

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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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11	AACHEN UNIVERISTY: PROCESS CONTROL ENGINEERING / AACHEN UNIVERISTY: INSTITUTE OF SOCIOLOGY	AAU	DE
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 titled D5.1 - *Wood composites specifications* is the result of task T5.1 – *Wood composites materials specifications definition* which is scheduled within the GREEN-LOOP project to be executed during the first months [M01-M04].

This report provides an overview of the final products expected from the wood composites value chain in terms of performance and technical characteristics as described in the GREEN-LOOP Project. LBRT, the end user, will test wood sliding bearings supplied by FHF in a relevant environment. LBRT, whose core business is the manufacture of bottle closures, will replace these bearings in one of their JSW injection mounding machines.

To test these prototypes, LBRT will conduct regular production cycles of varying length and duration. The data collected from these production cycles will be compared to cycles conducted on an injection moulding machine of the same brand and model that has not been modified. There might be an overlap between WP5 and WP4 as LBRT is the manufacturer for the prototypes of bio-plastic bottle enclosures developed during the activities of WP4. In this case a comparison between modified and non-modified machines will be done as well to assess the impacts of the modifications done. This analysis will take into consideration objective parameters such as:

- **Properties of current vs wood composite materials and bearings.**
- **Technical specifications of LBRT machineries and components.**
- **Legal standards to adhere to.**
- **Expected TRL level to be reached at the end of the activities.**
- **Future work and Upscaling.**

This document gives also a description of the current situation in the bearings manufacturing industry and why it is relevant to undergo metal bearings in favour of bio composite ones. Relevant aspects such as circularity, sustainability and environmental issues are taken into account. It also specifies which tasks will host specific activities and provides an estimate of the results WP5 hopes to achieve during the demonstration phase [M06-25].

Finally, a timeline for the demonstration activities at TRL6 regarding future work [M25-36] is outlined in the conclusive part of this report.

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Abbreviations

AI – Artificial Intelligence

DMP – Data Management Plan

DR – Air flow (%)

DSC – Differential Scanning Calorimetry

FTIR – Fourier Transform Infrared Spectroscopy

GA – Grant Agreement

I_{cl} – Clothes' Thermal Resistance ($m^2 \cdot °C/W$)

ICT – Information and Communications Technology

ISO – International Organization for Standardization

ISO VG - International Standards Organisation Viscosity Grade P_a – Partial pressure of water vapour in air (kPa)

PMV – Mean Expected Vote

PPD – Expected percentage of dissatisfied

RH – Relative Humidity

SEM – Scanning Electron Microscopy

T – Task

T_a – Forced ventilation room temperature (°C)

T_g – Globe temperature thermometer (°C)

T_o – Operating temperature (°C)

T_r – Average radiant temperature (°C)

T_w – Forced-air wet bulb temperature (°C)

TG – Thermo-Gravimetry

TU – Turbulence intensity

v_a – Air speed (m/s)

WC – Wood Composites

WP – Work Package

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1. Introduction

1.1. Purpose of this document

The purpose of this document is to describe all technical, chemical, mechanical, physical, and environmental characteristics needed to develop wood bearings for injection moulding machines that will be tested at LBRT’s facilities.

LBRT’s core business is aimed at the production of closures for spirits, which do have applications in other markets such as oil & vinegar, wine, and cosmetics. LBRT shares the same materials technologies, applications, and innovations to satisfy the different needs of their customers. Products are classified according to the material used for the head production, and stems can vary depending on the customer’s need.

Through the years, LBRT's production facilities have expanded to ensure quality and maintain control over our corporate standards. Their first step was toward insourcing centred on plastic moulding for the production of synthetic materials.

LBRT then added wood turning and started working with aluminium to round out its in-house capabilities. Vertical integration has enabled the company to monitor and inspect product quality from raw materials to finished goods, and with the development of these materials made from wood composites (WC), it is expected to reduce the environmental footprint of their manufacturing processes.

1.2. Need for new materials to mitigate environmental footprints

Steel, polymers and other materials are currently being used by the bearing industry for the manufacture of different bearing components. These bearing materials undergo different heat treatments and processes in order to attain the desired properties to maximize bearing life and performance. However, this leads to the emission of tonnes of CO_2 for every tonne of steel produced, plus the usage of heavy metals (mainly Pb, Cd, Sb, Cu and Sn) which are used in metallic bearings and are extremely dangerous for the environment. At the moment, there is no possibility to reduce the carbon footprint of conventional bearing materials.

From a greener perspective, the use of biobased materials aims to reduce the environmental footprint of the manufacturing process of these materials, reuse wood waste from other industrial or natural sources, and reduce maintenance costs. This goal can be reached by using materials that are derived from renewable sources like wood, with the added benefit of reducing the environmental impact related to its manufacture and improving their circularity.

2. General Workflow

The general workflow in the development of WC products for the bottle closures industry is included in the GREEN-LOOP proposal in the tasks of WP5. In the following subsections, the machines, in which wood composite bearings will be finally tested to demonstrate their feasibility, will be described to explain the operation conditions and requirements.

2.1. Characterization

2.1.1 Legal framework to operate with injection moulding machines

To be operative, all injection moulding machines must be compliant to the following standards:

- EN ISO 20430:2020
- EN ISO 12100:2010.

The first standard specifies the essential safety requirements for the design and construction of injection moulding machines for plastics and/or rubber processing and provides information for their safe use. This document is applicable only to injection moulding machines with hydraulic and/or electrical drives for platen movement. The standard deals with all significant hazards, hazardous situations, and occurrences relating to injection moulding machines, when used as intended and under conditions of misuse reasonably foreseeable by the manufacturer during the life cycle of the machinery (see ISO 12100:2010)

The second standard specifies basic terminology, principles and a methodology for achieving safety in the design of machinery. It specifies principles of risk assessment and risk reduction to help designers in achieving this objective. These principles are based on knowledge and experience of the design, use, incidents, accidents, and risks associated with machinery. Additionally, there are procedures described in detail for identifying hazards, estimating and evaluating risks during relevant phases of the machine life cycle, and eliminating hazards or sufficient risk reduction.

2.1.2 Essential characteristics of injection machinery and its bearings

The sliding bearings within the machine operate a repetitive movement for heavy load. For this, the slidings developed with the bio-based material must consider the following parameters:

- Load factor
- Temperature factor
- Dust factor
- Repetitiveness of the movement
- UV ray resistance
- Impact force
- Friction
- Lubrication

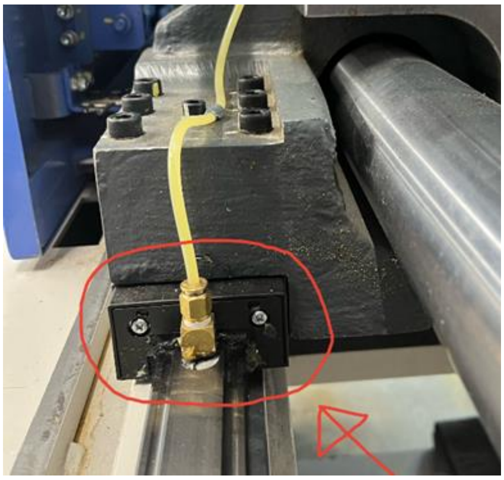

Figure 1. THK sliding bearing on JSW at LBRT

2.2 Standardization

The bio-material used for the sliding bearings will be produced in accordance with the following standards:

- ASTM D6866
- EN ISO 14125:1998
- EN ISO 1183:2019
- EN 15534-1:2014-04
- ISO 4378
- ISO 6691:2021
- ISO 4178-2

2.3. Data management

The management of this WP's data will involve several tasks from this and other WPs: task T1.4. "*Inline monitoring and quality controls*"; task T3.3. "*Upgrades and modifications of equipment in manufacturing lines*" and task T7.6. "*Open science and Data management plan*".

Throughout the duration of the project, IRIS will coordinate the collection of data from the three manufacturing lines onto the ICT (Information and Communication Technology) infrastructure that will be connected to the GREEN-LOOP platform for the purpose of optimizing the entire value chain, as well as the market analyses and identification of replication cases performed in WP7.

Additionally, in order to comply with the GDPR, RWTH AACHEN will also publish a Data Management Plan (DMP) that establishes the guidelines for data management (including the data collected, the data processed in the GREEN-LOOP platform, and the results obtained) throughout their entire lifecycle. This information will be published during M06 in deliverable D7.11 "*DMP and open sourcing approach*".

2.4. Circularity

In total, the activities performed in GREEN-LOOP aim to achieve a reduction in CO_2 emissions by 28% and waste material by 40%. To assure circularity and low environmental impact of the products it is necessary to develop solutions either to refurbish bearing components for reuse or to recycle the materials and produce new bearings from recycled base stocks.

A detailed list and a more deepened discussion will be presented in D2.1 *"GREEN-LOOP circular economy evaluation*".

2.5. Modelling

Modelling will be carried out by NCC as per task T5.3 "*Modelling, Eco design and manufacture of wood-based composite materials*", supported by AI models from task T2.5. All materials will be characterized by several methods such as TG/DSC, FTIR, SEM and grain size distribution. Samples and components with simple geometries will be manufactured by extrusion and press moulding. Quality controls on the WC samples will be performed by FHF and NCC by using non-destructive methods such as x-ray or ultrasonic.

2.6. Manufacture

Production of wood-bearing samples will be done by FHF in collaboration with NCC and UBRIS (T5.4).

The extrusion process will be performed and optimized by FHF using bio-based raw materials, in which samples for tribological testing and mechanical characterization will be preferentially performed in net-shape design. The surface of the specimens will be machined to assure certain lubricant retention, and compression tests according to ISO 604 will be carried out to a guarantee a minimum strength of the samples prior to the tribo-tests.

The compression moulding will be carried out at NCC using a hydraulic press and metallic tooling to produce panels. The panels can then be machined into the correct geometry for the slide bearing as defined above.

The panels will be pressed at the NCC using a HARE press. Some specifications of the HARE press:

- Platen Size = 0.6m x 0.6m (Maximum Tool area = 0.5m x 0.5m)
- Maximum Ram Stroke / day light = 0.5 m
- Max Pressing Pressure = 1,000 kN
- Max Closing speed = 300 mm/s
- Max Tool weight = 250 kg
- Maximum Platen Temperature = 400°C / 2°C per min (No Closed loop control)

2.7. Tribological testing and evaluation

Lab scale tribological testing of WC bearing materials and components will be performed by FHF (T5.5), this will include basic materials tests like Pin-On-Disc-Tests to determine friction coefficients and wear characteristics. These tests will enable screening of materials to identify most promising candidates for bearing materials, investigate tribological mechanisms and give advice for further materials optimisation possibilities.

For component tests, a basic bearing geometry will be used (see Section 3.1). These tests will be used to obtain information about general tribological behaviour und application-like conditions and thus evaluate the possibilities and limitations of WC for slide bearings, in general.

2.8. Demonstration

The products will be tested in an industrially relevant setting at LBRT’s facilities. The sliding bearing will be substituted in one of the available injection moulding machines to test their performance during the production of bottle closure. This particular demonstration overlaps with WP4 as one or more production cycles will produce samples with the bioplastic developed in said WP.

Iterations with T5.4 and T5.3 will be done to ensure the proper results at TRL5.

3. General Specifications

Specifications and applications of the bio-based wood composite are defined according to the current state and characteristics of the materials in use are given in the following table:

Table 1. Technical requirements for the wood composite final product

Product	Wood Composites	
Physical Properties	**Value**	**Units**
Density	Not relevant	-
Micro-porosity	Favorable to retain lubricant in the sliding contact	-
Water absorption	Acceptably low	-
Mechanical Properties	**Value**	**Units**
Tensile strength	> 50	MPa
Compressive strength	> 70	MPa
E-Modulus	> 1000	MPa
Thermal stability	Up to 150	°C
Tribological Properties	**Value**	**Units**
Wear Coefficient	$< 10^{-6}$	$Mm^3/(Nm)$
Friction coefficient	< 0.1 under lubrication < 0.3 under dry sliding	-
pv-value	> 0.3	MPa · m/s
Working conditions	**Value**	**Units**
Temperature	0 - 100	°C
Lubrication	Oil, grease	-
Standards to address		
ASTM D6866, EN ISO 14125:1998, EN ISO 1183:2019, EN 15534-1:2014-04, ISO 4378, ISO 6691:2021, ISO 4178-2		

3.1. General Shape after DIN 1850-6

This shape will be used for component testing at Fraunhofer:

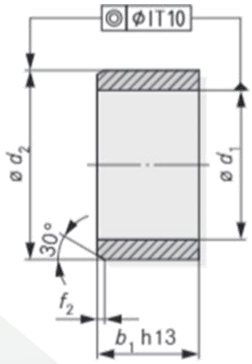

Figure 2. Component test at FHF (d1 = 10 mm, d2 = 16 mm, b1 = 10 mm, f < 0.5 mm)

3.2. General Shape for extrusion machine at LBRT

3.2.1 Microclimate conditions of the linear moulding department

In order to have information for future reference about the microclimate conditions of the location where the extrusion machine will be operating, a series of measures were taken on July 28th, 2022 at 9:23 a.m. lasting approximately 15 minutes for future reference. The measurement was done taking into account the following conditions concerning the correct transpiration of workers' clothing:

- Average metabolic activity: based on the tables provided by the standards (*UNI EN ISO 7730:2006, ISO CD7730, ISO/TC159/SC5 N201 Oct.2001, UNI EN ISO 7243:2017, Guideline of the Technical Coordination for Safety in the Workplace of the Regions and Autonomous Provinces*) is estimated to be 100 W/m^2 or 1.72 met

- Clothes' thermal resistance (I_{cl}): (again based on indicator tables) was estimated to be 0.50 clo equivalent to 0.0775 $m^2 \cdot °C/W$

Table 2. Microclimate Conditions - Linear Moulding Department

Measured environmental quantities	Average value		Units
Forced ventilation room temperature (T_a)	29.62		°C
Forced-air wet bulb temperature (T_w)	20.49		°C
Globe temperature thermometer (T_g)	29.79		°C
Relative humidity (RH)	41.87		%
Average radiant temperature (T_r)	29.85		°C
Air speed (v_a)	0.06		m/s
Turbulence intensity (TU)	23.86		%
Partial pressure of water vapour in air (P_a)	1.74		kPa
Well-being indices	**Calculated value**	**Guide value**	
Operating temperature (T_o)	29.71	23-26	°C
Mean Expected Vote (PMV)	1.64	±0.5	-
Expected percentage of dissatisfied (PPD)	58.34	<10	%
Air flow (DR)	1.79	<20	%

3.2.2 Injection Moulding Machines Information

The machines at disposal for this project are the following:

- (n°22) JSW 50 ADS – 60U, screw diameter 28mm, Linear Motion Guide n.4 THK SVS-30-LR

- (n°27) JSW 100 ADS - 180U, screw diameter 40mm, Linear Motion Guide n.4 THK SVS-35-LR

- (n°25) JSW 180 ADS - 300U, screw diameter 46mm, Linear Motion Guide n.4 THK SVS-45-LR

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All three injection moulding machines use an electric system, not a hydraulic one. They differ in tonnage, i.e. the closing force the machine is capable of. It should be noted that the injection unit must have sufficient clamping force to keep the mould closed to counteract the pressure of the plastic that will develop inside the mould cavity and cold runner.

Given the limited number of samples required for WP4, the smallest machine will likely be utilized. Bigger machines are normally utilized for extended-time productions, whereas smaller machines are generally used in short-time production and for product tests. These machines were evaluated in pairs for both WP4 (bioplastics) and WP5 (wood composites) in order to compare the performance of the modified machine and the unmodified machine. As the models under consideration are new, they do not include the component suggested by FHF. To prevent this problem, the following alternatives can be considered:

1. **Redesign the structure of the machines:** the skate that moves on spheres will be substituted by a sliding movement (unlikely).

2. **Use injection moulding machines JSW model AD, where the movement is given by two rollers fitted with pins with two bearings at each end (4 bearings total).** These machine uses an electric system and is equipped with the bearings proposed by FHF (likely).

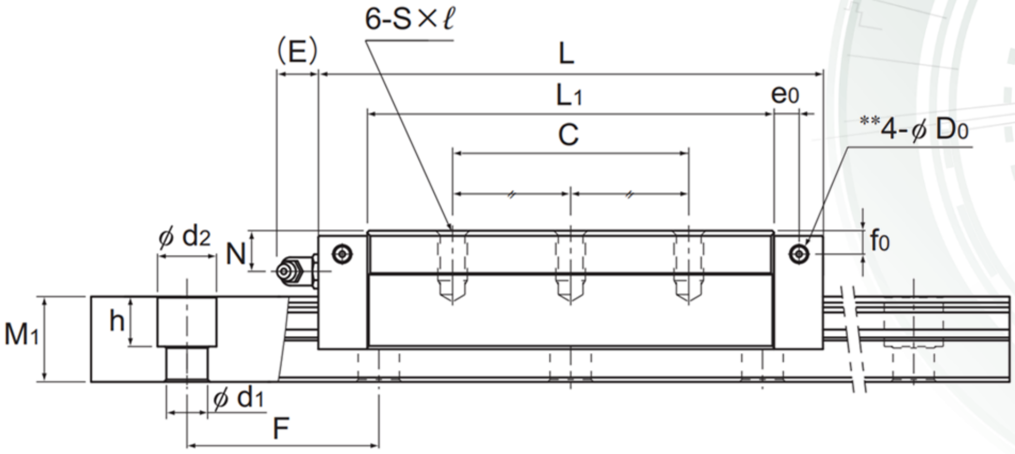
3. **Identify another type of machine at LBRT facilities, which presents cylindrical bearings in its mechanism** (in that case, there would be no more overlapping with the WP4 due to the modification of equipment not used for the manufacture of bio-plastic bottle closures)

4. **Propose a different element made with WC that is present in the moulding machine** (unlikely)**.**

3.2.3 Bearings Information

Regarding bearings on the ADS-series presses, the platen slides are on prismatic guides with carriages, and the columns are not guided on the platens (free without bushings); on the injection, the movement is all done with a ball screw that has bearings inside, but they are part of the screw itself.

LBRT machines use THK linear motion bearings, model SVS-LR. Models SVS have especially high rigidity and load carrying capacity among the Caged Ball LM Guide series. The raceway of models SVS adopts a circular-arc deep groove with a curvature approximate to the ball diameter. Since the ball contact area increases as the applied load increases, a large load carrying capacity is achieved and damping is also improved.



SVS-LR

Figure 3. SVS-LR model technical drawing (lateral)

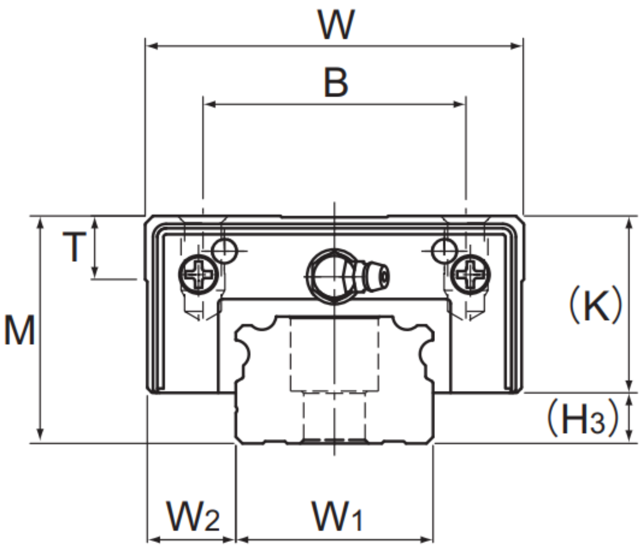


Figure 4. SVS-LR model technical drawing (frontal)

The following tables compile the main characteristics of the moulding machines:

Table 3. SVS-LR block technical data

Model N°	Outer dimensions (mm)			LM block dimensions (mm)												
	Height M	Width W	Length L	B	C	S x ℓ	L_1	T	K	N	f_0	E	e_0	D_0	Grease Nipple	H_3
SVS 30LR	38	69	120.5	40	60	M8x10	94.6	9.7	31	10.3	7	12	6.5	3.9	B-M6F	7
SVS 35LR	44	70	135	50	72	M8x12	104.5	11.7	35	12.1	8	12	6	5.2	B-M6F	9
SVS 45LR	52	86	171	60	80	M10x17	137.8	14.7	40.4	13.9	8	16	8.5	5.2	B-PY1/8	11.6

Table 4. SVS-LR LM technical data

Model N°	LM rail dimensions (mm)						Basic Load		Static permissible moment (kN/m)					Mass	
	W_1	W_2	M_1	F	d_1 x d_2 x h	$Length_{max}$	C (kN)	C_0 (kN)	One block			Double blocks		LM block (kg)	LM rail (kg/m)
									M_a	M_b	M_c	M_a	M_b		
SVS 30LR	28	16	21	80	7x11x9	3000	64.4	95.2	1.31	1.21	1.08	6.3	5.83	0.9	4.2
SVS 35LR	34	18	24.5	80	9x15x12	3000	86.1	123	1.88	1.73	1.67	9.15	8.46	1.3	6.0
SVS 45LR	45	20.5	29	105	14x20x17	3000	123	178	3.58	3.31	3.44	17.5	16.2	2.3	9.5

As for AD-series bearings’ dimensions or characteristics, further description will be given if chosen for this WP in deliverable D5.5 “*WC properties from tribological evaluation” at M12, in which* the selected bearing will be defined and described in detail.

3.2.4 Lubricant characteristics

Grease is used as lubricant for all machines. The product name is ***Bonnoc M220/JS1-EX***, supplied by JXTG Nippon Oil & Energy Corporation, and in the following tables its properties and composition are shown:

Table 5. Lubricant properties and composition

Properties	Value
Colour	Light yellow
Odour	Slight odour
Melting point/Freezing point	Dropping Point (250 °C)
Initial boiling point and boiling range	No data
Auto-ignition temperature	Explosion Limit (1-7%)
Vapour Density	No data
Density (g/cm^3)	No data
Solubility	Water: Insoluble
Partition Coefficient	No data
n-octanol/water	-
Decomposition temperature	No data
Compounds	**Concentration wt. %**
Base Oil(s)	80 - 90
Thickener	10 - 20
Additives	<10
2,6-Di-tert-Butyl-4-Cresol	0.1 - 0.9

In this setting, it is recommended to use industrial high-pressure transmission oil (ISO-VG220). The manufacturer recommended brands of lubricating oil (transmission oil) are the following:

- Bonnoc M220 supplied by JX Nippon Oil & Energy (in use).
- Dahpne Super Gear Oil 220 supplied by Idemitsu.
- Omala S2 G 220 supplied by Showa Shell Oil.

If the hydraulic oil recommended by JSW is not available, it is recommended by the machine’s handbook to use an oxidation stabiliser equivalent to the HM46 of the International Organisation for Standardisation ISO 3498, and refined petroleum that has anticorrosive and abrasion-resistant properties, as listed below:

- **Kinetic viscosity:** 41.4 to 50.6 cSt/40 °C (104 °F)
- **Viscosity exponent:** 95 or more
- **Flammability tip:** > 200 °C (392 °F)
- **Fluidity point:** -12.5 °C (-9.5 °F)

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4. Future workflow and Upscaling

The substitution of the linear motion bearings that are currently in use by WC sliding bearings will require a re-design of the carriage to ensure that these bearings will have the required stiffness and load carrying capacity.

The further development of the WC bearings will follow the work description of the WP5 of the Grant Agreement (GA) as well as the general workflow describe in section 2 of this report. This will include materials and manufacturing development, lab-scale analysis, and testing activities.

Manufacture of the bearings will be done either by extrusion only or by extrusion followed by compression moulding with the enhancements detailed in task T5.2 "*Upgrades and modifications of equipment in manufacture lines*"

During M06-M025 will be performed in task T5.3 "*Modelling, Eco-design and manufacture of wood based composite materials*" and T5.4 "*Generation of samples, characterization and quality control*" a continuous work of data control and upgrades to deliver a solid prototype.

The extrusion of these prototypes with the final geometry will be tested at TRL6 in industrial setting by LBRT. All quality characteristics defined previously will be constantly reviewed during M25-M36 in the activities of WP6.

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5. Conclusions

Specifications were defined according to discussions in the consortium about the typical requirements of thermoplastic composites and the specific requirements for bearings to be used in moulding machines at LBRT. These specifications will be used as a guide for subsequent tasks within WP5, i.e., to find, manufacture and evaluate suitable compositions and eventually demonstrate their use as technical bearings.

It is necessary to define which machine model will be used to test the bearings as the information for the part to be substituted will vary accordingly. As previously stated, due to the quantity of samples necessary, it is likely that the smallest machine will be utilized. Typically, larger machines are employed for extended-duration manufacturing, whilst smaller machines are more suited for short-duration productions and product testing. Consequentially, this choice will affect measurements and characteristics of the bearing features themselves.

Lab scale demonstration and evaluation will help define and find ulterior attributes of the WC bearings, which also will affect the products obtained in the bio-plastic value chain during WP4, as LBRT is the manufacturer. Finally, the last tasks of the WP5 will be to evaluate the tribological performance of the WC materials and bearings to demonstrate their feasibility for technical use.

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Annex A: List of standards applicable to the WC value chain

- **ASTM D6866** Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis.
- **DIN 1850-6:1998** Plain bearings - Part 6: Thermoplastic bushes.
- **EN ISO 14125:1998** International Standard for determining the flexural properties of fibre-reinforced plastic composites under three-point (Method A) and four-point (Method B) loading.
- **EN ISO 1183:2019** Plastics - Methods for determining the density of non-cellular plastics - Part 1: Immersion method, liquid pycnometer method and titration method.
- **EN 15534-1:2014-04** Technical Standard for Composites made from cellulose-based materials and thermoplastics - Part 1: Test methods for characterisation of compounds and products.
- **ISO/CD 7730 ISO/TC159/SC5 N201 Oct.2001** Ergonomics of the thermal environment — Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.
- **ISO/TR 3498:1986** Lubricants, industrial oils and related products (class L) — Recommendations for the choice of lubricants for machine tools.
- **ISO 4378:2017** Plain bearings — Terms, definitions, classification and symbols – Part 1: Design, bearing materials and their properties / Part 2: Friction and wear / Part 3: Lubrication.
- **ISO 4378:2009** Plain bearings — Terms, definitions, classification and symbols – Part 4: Basic symbols / Part 5: Application of symbols.
- **ISO 4378:2012** Plain bearings — Terms, definitions, classification and symbols — Part 6: Abbreviated terms.
- **ISO 6691:2021** Thermoplastic polymers for plain bearings — Classification and designation.
- **ISO 4178:1980** International Standard for Complete, filled transport packages — Distribution trials — Information to be recorded.
- **ISO 604:2002** International Standard that specifies a method for determining the compressive properties of plastics under defined conditions.

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- **Guideline of the Technical Coordination for Safety in the Workplace of the Regions and Autonomous Provinces** Microclimate, ventilation and lighting in workplaces: requirements, standards, operational and design indications.

- **UNI EN ISO 7243:2017** Ergonomics of the thermal environment — Assessment of heat stress using the WBGT (wet bulb globe temperature) index.

- **UNI EN ISO 7730:2006** Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.

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