Multi-level Circular
Process Chain for Carbon
and Glass Fibre Composites

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Deliverable D6.7: Design of civil engineering part: joining collets for pipe lines

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SEN	Sensitive information	

Contents

1. OBJECTIVE

The objective of D6.7 is the design of composite joining collets containing recycled fractions for steel and composite pipelines. Growing demand on such construction as joining collets is strictly connected with increasing market for pipelines for gas and liquid fuels and other e.g. mining products as well as with demanding working conditions, thus there is a common need to find appropriate solutions to fabricate mechanically and environmentally resistant components which withstand sophisticated conditions and for which it will be possible to apply materials achieved from recycling.
Pipelines are used to transmit various types of media in many industries. In the case of a product intended for underground hard coal mines, they are used for ventilation, transport of water and water suspensions, transport of chilled water in air-conditioning systems, supply of process water, transport of hydraulic backfill and transport of output in processing plants. Pipelines transport crude oil and gas, as well as various types of substances with special mechanical and chemical properties.
Depending on the recipient group, the market needs are similar. Pipelines should be light and characterized by "longevity" of the structure, quick and cheap to install compared to heavy steel structures, have increased thermal resistance and be characterized by a variety of types of connections and assembly methods. In Poland, many networks and installations still use pipes made of steel, stoneware and cast iron. This is due to the fact that many of them are used for a much longer period of time than the manufacturers' recommendations, and the prices of individual elements, due to high availability, are often lower than modern structures made of synthetic materials. It is worth pointing out that in many coal mines in Poland, the pipe loses its properties due to abrasion after approximately 2 years of operation and should be replaced after that time. However, mainly due to cost savings, the pipelines are "rotated" by 90 degrees and reused.
It often happens that a pipe with a manufacturer's warranty period of 2 years is used for 8 or more years, which in turn translates into a significant reduction in the safety level of the entire installation. The answer to the above mentioned issue could be a new technology of pipes and their components e.g. joining collets made of composite material. Global demand for plastic pipes is expected to increase by 4.6% per year, reaching 18.1 million tons in 2020. The numerous advantages of this material justify the use of composites for pipe production. One of them is the seamless adjustment of functions, dimensions, colors and parameters related to strength and resistance (e.g. to chemically aggressive media) to the individual needs of the customer. Another advantage is the very low weight composite structures. For example, composite elements constitute only approximately 10% of the weight of a comparable reinforced concrete structure, approximately 20% of the weight of a steel structure and approximately 25% of the weight of a malleable cast iron structure. This aspect of composites allows you to largely eliminate the use of heavy equipment, e.g. for laying pipelines or transporting ready-made elements, which in turn reduces investment costs. Additionally, the lower weight compared to steel pipes makes storage, loading and transportation much easier and cheaper. The use of composites for thin-walled elements is also supported by their high durability and reliability, manifested, among others, by: corrosion and aging resistance. As proven by tests on the durability of laminates conducted in American and Scandinavian laboratories, the service life of composites is not less than 50 years, and the strength after 50 years is at least 80% of the initial strength.
It should be noted that in addition to numerous advantages such as strength and resistance, the assembly of composites is much easier. Laying a pipeline consisting of this type of pipes is very simple because the pipe is unwound from a special spool. Additionally, the problem of welding sections disappears, which saves approximately 40-80% of the time when laying the pipeline (6 km of pipeline can be laid per day), as well as 35-65% of the costs of this operation. Installation of pipelines made of composite pipes is possible using fewer workers, as there is no need to use radiography to check welded joints. Another undoubted advantage is the lack of corrosion in composite pipes and the ability to transport chemicals that accelerate corrosion (chemically aggressive liquids).

According to the report "Fiberglass Pipe Market Analysis, By End-use (Oil & Gas, Chemicals, Sewage, Irrigation), By Region (North America, Europe, Asia Pacific, Central & South America, MEA), And Segment Forecasts, 2018 – 2025" (Grand View Research, August 2017) in 2016, the global market for fiberglass pipes was worth USD 3.83 billion. This report also forecasts significant market development in the years to come 2018-25, which is driven by the demand for lightweight, fire- and corrosion-resistant pipes.
Major industries using composite pipes include oil and gas, irrigation, chemical, and sewage industries. It must be noted, that the most important recipient of this type of pipes is the oil and gas sector. In 2016 it accounted for 41.9% of the global share in the sector's revenues. Other important industries are the chemical and irrigation industries. Sector is driven mainly by the glass fibres epoxy product segment, which is used in the creation of marine and onshore pipelines, necessary for oil and gas extraction. The above-mentioned report predicts a large development of the fiberglass pipes market in North America and Europe, which is caused by falling prices of natural gas, which is used as a raw material in many branches of the chemical industry. Another important recipient is the construction industry.
The GRE segment was the largest market segment and generates the highest revenues. It is estimated that by 2025 will be worth USD 3.14 billion and the cumulative annual growth rate will increase by 5.3% between 2018 and 2025. The main advantages of GRP pipes are: low weight with high mechanical strength, resistance to chemicals and corrosion (thanks to its dielectric properties, it is also resistant to corrosion, resistance to UV radiation, temperature stability. Polymer composites are suitable for applications that operate under extreme pressures and thermal conditions and require high corrosion resistance, i.e. industrial and marine oil and gas pipelines.

2. GENERAL PART DESCRIPTION

In many cases, pipelines and their components such as joining collets are exposed to numerous harmful factors. During the construction and use of gas pipeline systems, the following criteria are taken into account:

- ensuring the safe use of gas pipelines,
- maintaining the required level of operational reliability,
- meeting environmental protection requirements,
- reducing use and maintenance costs,
- increase in operating efficiency.

In turn, the mining and fuel transportation industry attaches great importance to the following aspects:

- physical and mechanical properties of the material from which the joining collets are made,
- resistance of the pipe material to environmental factors - mechanical, chemical, physical and biological,
- stability of mechanical properties of pipes,
- maintaining operational parameters.

The images below (Figs. 1-3) present part geometries which were designed as joining collets.

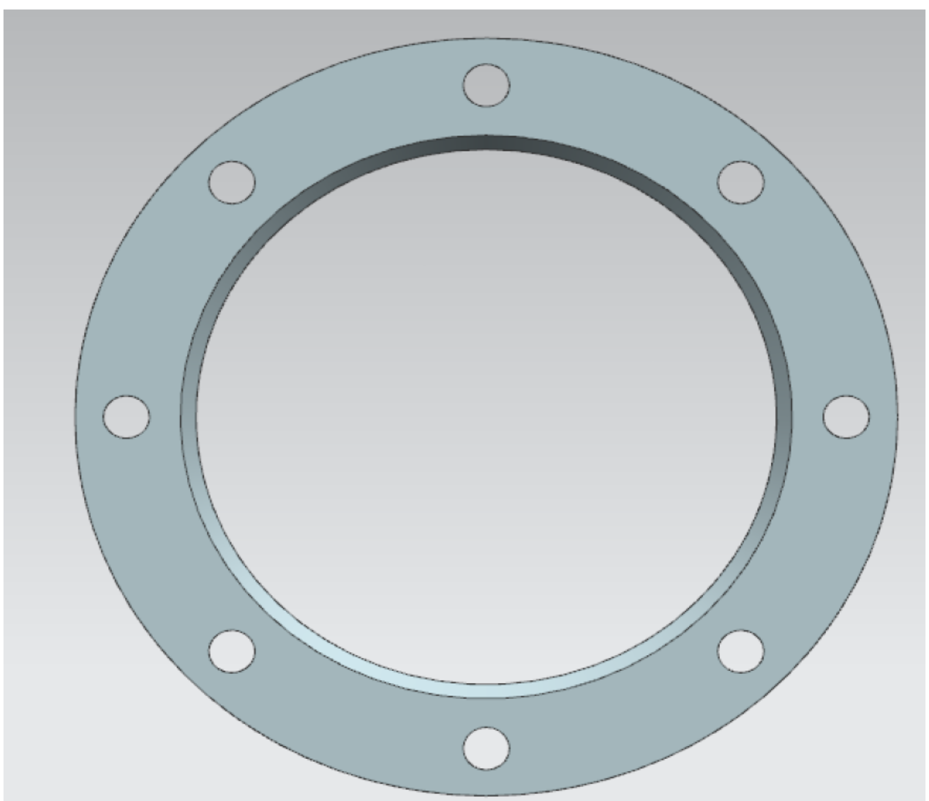

Fig. 1: Scheme presenting joining collet's geometry.

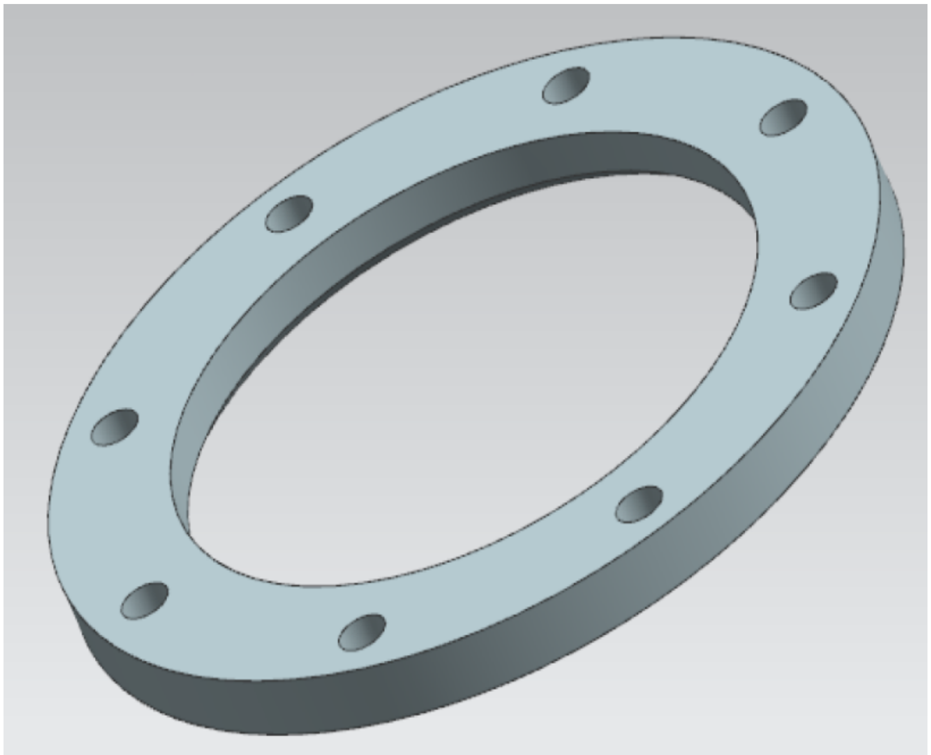

Fig. 2: Scheme presenting joining collet's geometry.

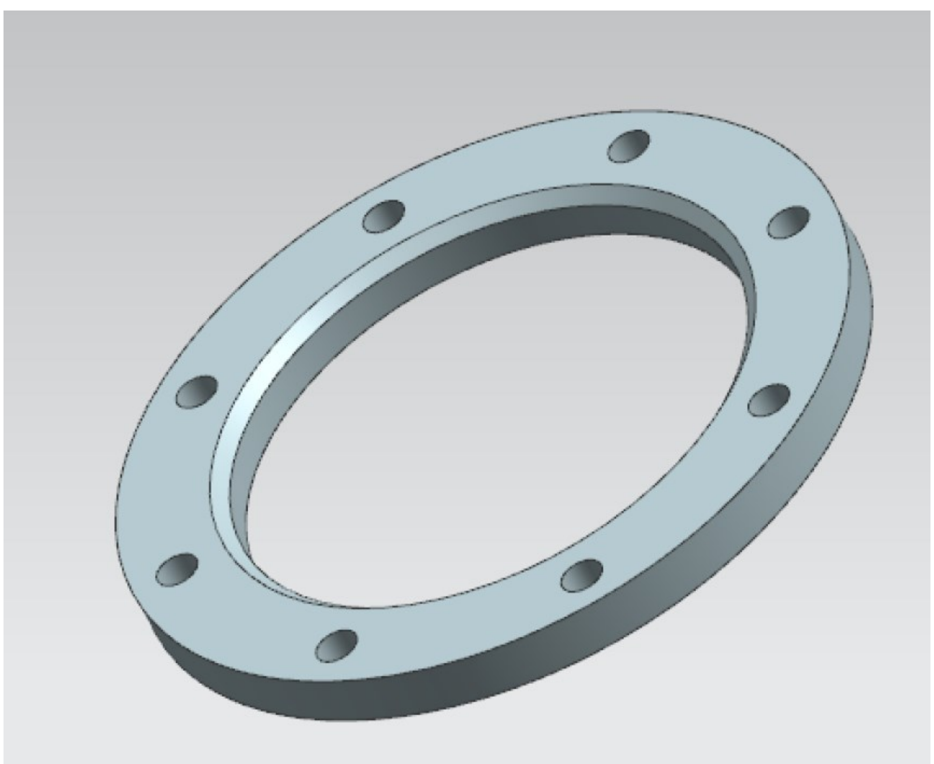

Fig. 3: Scheme presenting joining collet's geometry.

2.1 Technology for manufacturing

2.1.1 Method of production

The fabrication of composites by 'compression molding' is a common method for producing composite materials with specific shapes and properties. This process often involves combining reinforcing fibers and particles with a matrix material, and then compacting the mixture into a mold under pressure. The challenges with the fabrication of the composite components containing recycled material fractions cover the following aspects connected with especially poor compatibilities between neat resin and recycled fractions, low wettability of the recycled surfaces, different behaviour during fractions infiltration with liquid resin, different viscosity due to not standard geometry of recycled fractions etc. Below is a general overview of the fabrication process by means of pressing material into the molds for fabrication of composite joining collets:

1. Materials selection:
    - Selection of materials and matrix material was based on the desired properties of the final composite. Reinforcing materials include fibers retrieved from solvolysis process and optionally grinded GFRP particles, while matrices constitute the NOMA amin epoxy resin.
2. Preparation of reinforcements and matrix:
    - The reinforcing material (fibers or particles) and the matrix material are prepared in advance. This may involve cutting fibers to the desired length, impregnating fibers with the matrix material, or mixing particles with the matrix.
3. Mold Preparation:
    - A mold is prepared based on the desired shape and dimensions of the final composite product which constitute joining collets for pipelines. The mold is designed to be made of metal in order to ensure sufficient mechanical properties and durability.
4. Mixing:
    - The reinforcing material and matrix material are mixed before the mixture will reach the mold. The arrangement of the reinforcing material and the distribution within the matrix influencing the final properties of the composite.
5. Pressing into Mould:
    - The layered or mixed materials are then subjected to pressure within the mold. This can be done at room temperature (cold pressing) or at an elevated temperature (hot pressing). The application of pressure helps to compact the materials and ensures intimate contact between the reinforcing and matrix components.
6. Curing:
    - In this step the composite undergo a curing process where the polymer is hardened according to the resin specification in order to provide maximal mechanical strength of the final product.
7. Cooling and Demolding:
    - After the pressing and curing process, the composite is allowed to cool down. Once cooled, it is demolded, and excess material is machined to achieve the final desired shape.
8. Post-Processing:

- Depending on the specific requirements of the applied epoxy resin, additional post-processing steps such as annealing in at a certain temperature is conducted to ensure full curing of the component.

Press for fabrication of components of joining collets is presented below in Fig 4.

Fig. 4: Press for fabrication of components of joining collets.

2.1.2 Materials for components fabrication.

Description below summarizes materials which will be used for fabrication of joining collets. Taking into account, that NOMA is a producer of epoxy based resins, the formulation of the resin can be directly adjusted for the project and components needs. Time of curing process, characteristic temperatures, viscosity etc. can be changed to fit process requirements.
Due to the excellent wetting properties of virtually any fillers and fibers available on the market, including glass, carbon, aramid and basalt fibers, **NOMA Comp** is widely used by manufacturers in transportation industry, marine, sport and even avionics and aerospace industry. Below there are collected processing parameters of NOMA resin (Table 1).

PROCESSING PARAMETERS							
		RESIN (A)			HARDENER (B)		
PARAMETER	**UNIT**	**ULV**	**LV**	**MV**	**HR**	**MR**	**LR**
Viscosity (at 23°C)	mPas	300-350	500-600	1200-1600	< 20	< 20	< 20
Density (at 23°C)	g/ml	1,05	1,11	1,20	0,95	0,92	0,92
Mixing ratio	phr		100		30	28	31
					Mixture		
Pot-life (100 g / RT, at 23°C)	approx. in minutes				30	60	120

Table 1: Parameters for processing of NOMA resins.

It is not common for the NOMA resins to crystalize. But it is highly recommended to keep all NOMA products in closed, humidity-free containers under temperatures between 15-30 ^{o}C. In case some clouding happens in the resin one can heat-up the resin to ca. 50 ^{o}C to remove any traces of crystallization. Do not heat the resin with the open fire. Always warm up opened containers to avoid pressure built-up**.** Hardeners tend to crystallize. It should be stored free from moisture and carbon dioxide. As partial precipitation can cause a change in the isomer ratio of the before mentioned products in the liquid phase, it is necessary to completely liquify the entire contents by warming (max. 60^{o}C) and stirring. Table 2 shows mechanical parameters of NOMA resins systems.

MECHANICAL PARAMETERS					
		SYSTEM			
PARAMETER	**UNIT**	**ULV/HRLV/HR MV/HR**	**ULV/MR LV/MR MV/MR**	**ULV/LR LV/LR MV/LR**	**STD.**
Density	g/cm^3	1.14 1.18 1.17	1.14 1.16 1.15	1.14 1.11 1.12	ISO 1183
Impact strength	kJ/m^2	90 77 89	82 78 77	81 90 88	ISO 179
HDT	°C	81 77 78	82 80 80	82 77 78	ISO 75A
Tensile strength	MPa	83 79 88	87 80 77	85 85 84	ISO 527-2
Young modulus	GPa	3,3 3,1 2,9	3,2 3,0 3,0	2,8 3,0 2,9	ISO 527-2
Flexural strength	MPa	119 122 125	128 130 134	124 128 125	ISO 178
Flexural modulus	GPa	3,1 3,2 3,1	3,2 3,3 3,3	3,3 3,2 3,2	ISO 178
Elongation at break	%	7,0	8,0	6,8	ISO 527-2
Compressive strength	N/mm^2	> 100	> 100	> 100	ISO 604
Absorption of water after 7 days	%	< 0,5	< 0,5	< 0,5	ISO 175

Table 2: Mechanical parameters of NOMA Comp after post-curing at 60°C, 4h

As the reinforcement it is planned to use recycled material in the form of grinded GFRP originated from VDL composite side walls or composite wind turbines as well as alternative products retrieved from solvolysis process. The images below (Fig. 5) show ground GFRP composites prepared for composite joining collets fabrication.

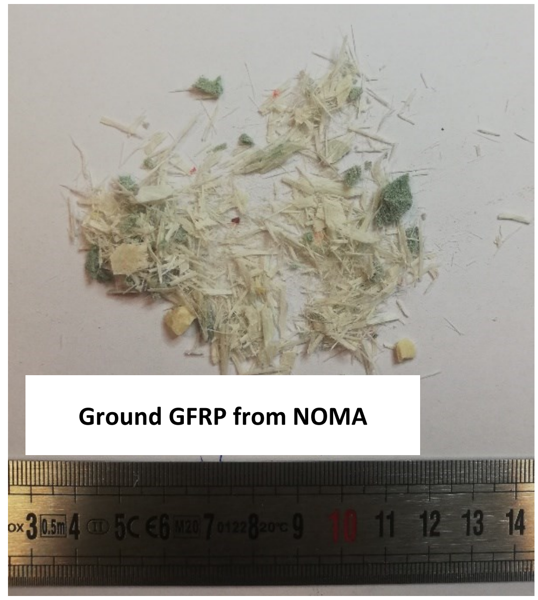

Fig. 5: Images for grinded GFRP material delivered by VDL (left), NOMA (right).

2.1.3 Mold type

Metal molds play a crucial role in the fabrication of polymer composites. These molds are used in various processes such as injection molding, compression molding, and transfer molding. Metal molds are used in polymer composite fabrication in different processes:

1. Injection Molding:
    - Process: In injection molding, a molten polymer composite is injected into a metal mold under high pressure. The material then cools and solidifies, taking the shape of the mold.
    - Materials: Metal molds for injection molding are typically made from materials like aluminum or steel, depending on the production volume and the specific requirements of the composite material.
2. Compression Molding:
    - Process: Compression molding involves placing a pre-measured amount of polymer composite material into an open mold cavity. The mold is then closed, and pressure is applied to compress and shape the material.
    - Materials: Steel is commonly used for compression molding molds due to its durability and ability to withstand high pressure and temperature.
3. Transfer Molding:
    - Process: Transfer molding is similar to compression molding but involves a preheated material being pushed into the mold under pressure. This process allows for more complex shapes and precise control over the molding process.
    - Materials: Steel or aluminum alloys are often used for transfer molding molds.
4. Advantages of Metal Molds:

- Durability: Metal molds are durable and can withstand the high temperatures and pressures associated with polymer composite fabrication processes.
- Precision: Metal molds allow for the production of high-precision components with consistent quality.
- Longevity: With proper maintenance, metal molds can have a long lifespan, making them cost-effective for large production runs.

5. Considerations:

    - Material Compatibility: The choice of metal for the mold should consider the compatibility with the polymer composite being used.
    - Surface Finish: The surface finish of the mold affects the final appearance and quality of the molded composite. Surface treatments like polishing or coatings may be applied.

6. Maintenance:

    - Regular maintenance is essential to prolong the life of the metal mold. This includes cleaning, inspection, and, if necessary, repairs or reconditioning.

7. Cost Considerations:

    - The cost of metal molds can vary depending on the material used, complexity, and size. However, the durability and precision they offer often justify the initial investment.

Below, the designed and fabricated moulds for manufacturing of composite joining collects contained ground GFRP and/or carbon fibres are presented.

Fig. 6: Images of metal mould for joining collets fabrication

2.2 Technical specifications

As it was mentioned previously, taking into account working conditions of pipe lines components such as pipes and joining collets and specification of the industrial branches where they are utilized, designed components need to fulfil mainly the following requirements:

- resistance of the pipe and joining collets material to environmental factors - mechanical, chemical, physical and biological,
- stability of mechanical properties of the composites especially in fatigue cycles,
- thermal and dimensional stability of composite components during operating conditions,
- maintaining operational parameters and maintenance,

In the case of joining collets it is not necessary to provide any specific outer look or surface finishing.

2.3 2D plans

The Fig. 7 presents the general design of joining collets dedicated for fabrication by pressing technology utilized by NOMA. The component is considered to consist recycled fractions delivered within project.

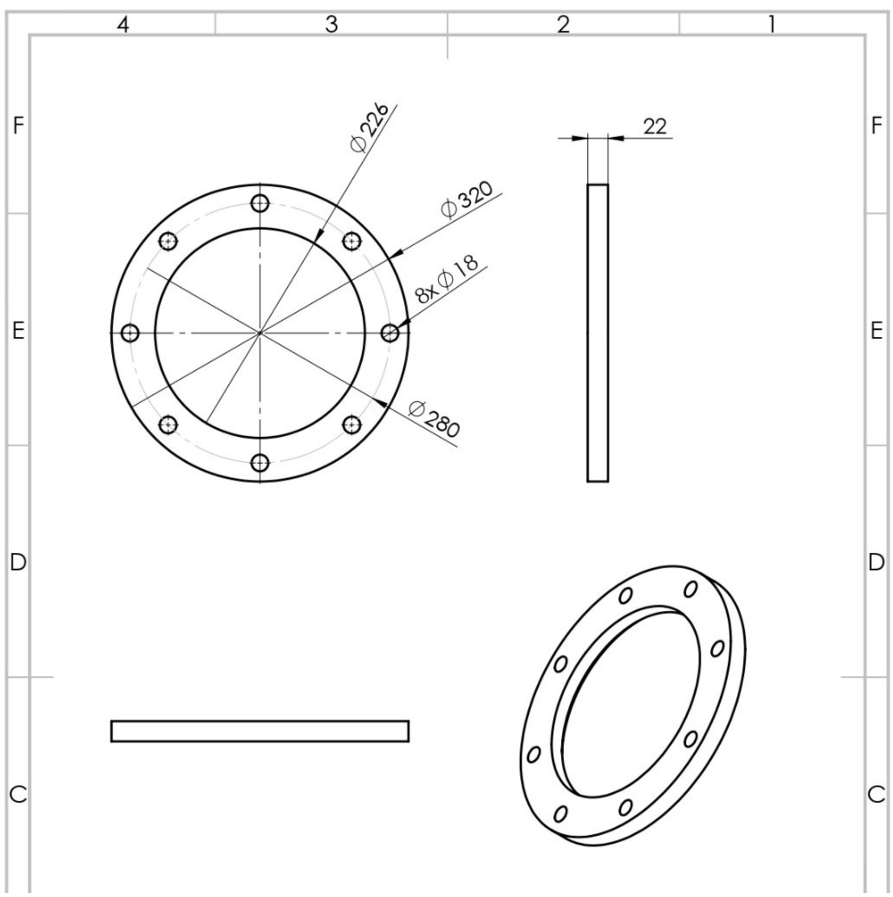

Fig. 7: 2D scheme of joining collets with indicated dimensions.

3. CONCLUSIONS

Currently, there are no composite joining collets containing recycled material fraction on the market dedicated to the mining and fuels transportation industries that would enable the creation of fully safe pipelines that meet the high requirements of the industry, while ensuring intuitive, cheap and easy-to-use installation. Additionally, customers expect the required level of operational reliability and installation compliance to be maintained with the most current environmental protection requirements. It is assumed that the implementation of the MC4 project will increase the efficiency of the entire installation and influence the overall level innovation of the mining industry and energy transmission in the country and in the rest of Europe. The implementation of the project results concerning joining collets with recycled material will contribute to the significant development of pipe markets composites in many countries of the Europe, because products with such parameters are currently unavailable on the domestic market.