Experimental verification of high-strength composite materials using a simulation program

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Abstract. The use of composites in engineering applications has been steadily growing in recent years. Despite this growth and despite some important advantages of the properties that composites offer, such as reduced weight, design freedom, etc., a breakthrough in high-volume components in engineering applications has not been achieved at present. Therefore, when designing selected parts and structures using new materials, such as composites, material and manufacturing costs must be considered a high priority if further significant growth is achieved. However, many other factors must also be considered when designing a composite part for engineering use. These factors also depend on the particular material or combination of materials being evaluated. The paper is focused on testing a composite material manufactured from polybutylene terephthalate (PBT), reinforced with high-strength fibres Cordenka and Aramid fibres. The composite material's mechanical properties were verified using Ansys simulation software.

1. Introduction

Composite materials form a very wide and important range in engineering applications [1]. They originate in natural materials such as wood, bone or teeth, composites with a complex internal structure formed with mechanical properties suitable for the specific applications in which they are applied [1], [2]. They are defined as a system of separate phases that differ significantly from each other. Still, they together form a system having properties that none of the substances used alone would have. There is a synergistic effect, which means the suppression of negative properties, but the highlighting of the previous ones. The phases have different physical, mechanical and chemical characteristics and are insoluble in each other [2]. For a multiphase material to be classified as a composite material, it should meet the following conditions:

- it must be prepared by mixing the ingredients,
- the proportion of filler,
- reinforcement must be more than 5%.

The properties of the filler or the reinforcement and the matrix must differ significantly [3]. The composite usually consists of a solid component embedded in a finer component, the matrix. The term solid component can be understood as a filler or reinforcement, either in particles or fibres [2]. We can divide it into two general groups; particle-filled composite materials and fibre-reinforced materials [4].
Thanks to the constant progress of research and development of new technologies in engineering (automotive industry, railway industry), electrical engineering, and materials, it is clear that there will be a huge increase in the production of composite materials soon. These materials are more useful in the automotive, engineering, aerospace, and railway industries due to lighter and more durable materials that require rapid maintenance [3].

Due to problems with rust and rapid weathering and corrosion of materials, PBT materials can be a suitable metal replacement and, depending on their selected properties, can withstand adverse effects and are ideal for a variety of construction applications and are not subject to complex maintenance. New types of PBT have been developed that offer better results in laser welding, providing a unique, smart solution for welded parts. [4] Due to the volatility of the PBT market, it is mostly used to manufacture electronic and electrical components. In North America, Japan and Europe, PBT materials are mostly used in the automotive industry [5], [6].

According to statistics on PBT production, by 2020, Asia has significantly increased its production compared to Europe and other continents. It is mainly due to many foreign investments in this area and the need for materials with lower production costs, which is impossible in many Western countries [7].

2. Research Methodology

The use of plastic-based composite materials in engineering applications has grown steadily in recent years and is expected to show further growth by 2030. Despite some important advantages in the properties that plastic-based composite materials offer (e.g. reduced weight, design freedom, etc.), a breakthrough in the field of components in large volumes of automotive and railway applications has not been achieved. There are many reasons, but last but not least, the key issue is mainly in the area of costs and production itself. Where there have been significant changes, especially in non-structural and semi-structural applications, cost-effective manufacturing has been key to the adoption of composites. Structures with the use of new materials, mainly composites, were used to design automotive and railway components. Due attention must be paid to material and production costs, as an important aspect if further significant growth in use is to be achieved. Many other factors must be taken into account when designing a composite part for automotive and railway services. The factors depend on the particular input material or combination of materials used and the function of the position. The presented paper aims to find an effective way to use composite materials based on PBT matrix and reinforced by high-strength fibres aramid and Cordenka.

2.1 Matrix and Filler

Polybutylene Terephthalate, PBT (Fig. 1), is an important thermoplastic in engineering plastics and is available in many different modifications - e.g., a mixture with other plastics materials, e.g. PC, ASA or PET [5]. The presented research is a basic component of the preparation of a composite material, where it forms a matrix. The material is characterized by good mechanical properties, chemical resistance and dimensional stability [6]. Pure PBT is an ideal candidate for this use (Table 1).

| Table 1. Key Properties of Polybutylene terephthalate [7]. |
|----------------------------------------------------------|
| **Mechanical Properties**                                 |
| Elongation at Break [8]                                   | 250 |
| Hardness – Rockwell                                       | M70 |
| Izod impact strength [8]                                  | 60  |
| Tensile modulus [8]                                        | 2   |
| Tensile Strength [8]                                      | 50  |
| **Physical Properties**                                   |     |

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| Property                      | Value       |
|-------------------------------|-------------|
| Density [8]                   | 1.31        |
| Limiting oxygen index        | 25          |
| Water absorption over -24 hours [8] | 0.1         |

**Thermal Properties**

| Property                      | Value   |
|-------------------------------|---------|
| Heat- Deflection temperature - 0.45 MPa [8] | 150     |
| Heat-deflection temperature - 1.8 MPa [8]  | 60      |
| Upper working temperature [8]   | 120     |

This product group meets the higher demands on flame retardancy with small wall thicknesses. For this reason, this material can be used wherever high orders are placed on flame retardancy and heat resistance [8]. These include covers for electrical engineering, connectors in the vehicle and in the engine compartment, and parts in the lighting industry.

Aramid fibres (Kevlar) (Fig. 1), with excellent heat resistance and low flammability, are unusual in that they do not melt - they only begin to degrade (at about 500 degrees Celsius) [9]. They also have very low electrical conductivity, which makes them ideal electrical insulators [10]. Due to their high resistance to organic solvents, the versatile "inert" aspects of these materials offer excellent versatility for various applications [11]. They are sensitive to UV radiation, acids and salts. They also generate static electricity unless specially treated [12]. These fibres' excellent properties have provided advantages that make them ideal for a wide range of applications.

The Cordenka (Fig.1) used in the research is a special technical viscose yarn with unique properties suitable for high-performance applications [13].

![Polybutylene Terephthalate (PBT) reinforced with high-strength fibres.](image)

*Figure 1. Polybutylene Terephthalate (PBT) reinforced with high-strength fibres.*
The chemical composition of the filler has little impact on its use in composite materials. Still, it plays two most important roles, namely the mineral structure and the interaction between the filler and the matrix [14]. The compact's additional physical characteristics are also needed to predict their suitability and success for specific applications in the composite material used [15].

2.2 Ansys Software

The first possible use is for engineering applications. From the material point of view, it is the most important part that needs to be defined because it is the part where technical data is entered [16], the material properties for two different composites (Fig. 2). The linear elastic tab was selected on the toolbar, and we defined the isotropic elasticity and under it changed the Young's modulus [17] according to the results from the graph obtained by the tensile test, and then changed Poisson to 0.4, which is the standard ratio for composites. An air duct [18] is commonly used inside for an air ventilation system, which may be, for example, an air conditioning unit or an air intake duct into a filter or even into an engine manifold for mixing fuel and air [19]. It is important to assume all possible parameters for the fibres to be analyzed. In general, the air duct (Fig. 2, Fig. 3) is a component made of commonly used plastics, but by using composite reinforcement, we can increase its application possibilities. According to our results, we can state that the materials have good elasticity. It is crucial for air ducts, and it is a good choice because it must withstand the force that can come from any source.

![Figure 2. Selected component designed in CATIA.](image)

Subsequently, the "Static structure" option was selected to enter fixed support and force (Fig. 3). We have chosen the option of inserting improved support for the static structure [1], [20]. Subsequently, we selected both holders in the geometry.
The last item in the simulation is the "Solution" itself. Total deformations, equivalent stress were inserted. After entering the input data into the simulation software Ansys, the simulation of individual composite materials began [21].

### 3. Results and discussion

We focused on testing a composite material reinforced with high-strength aramid and Cordenka fibres as part of the research. Ansys simulation software was used to simulate mechanical properties. Ansys is the most suitable software for simulating a product using finite element analysis and for simulating the problem itself [22]. Using Ansys software, larger structures are broken down into small components that are individually modelled and tested separately [23]. It begins by defining the object's dimensions and then adding weight, pressure, temperature and other physical properties [24]. Ansys software simulates and analyzes motion, fatigue, fluid flow, temperature distribution, electromagnetic efficiency, and other effects over time [25]. Our research focuses on mechanical properties. Tensile testing is crucial for the selection of suitable materials during research and development [26]. Tensile tests may also be used to verify that the materials comply with the minimum strength and elongation requirements [27]. The use of unsuitable materials can result in significant losses [28]. PBT-aramid (Fig. 3), Young's modulus for aramid is calculated as 73131 MPa using the tensile test results.

The results of the total deformation are identified and presented in Table 2. Figure 4 shows the total deformation of the material using a high-strength Aramid fibre.

| Time [s] | Minimum [mm] | Maximum [mm] | Average [mm] |
|----------|--------------|--------------|--------------|
| 1.       | 0            | 7.4648       | 1.946        |

**Figure 3.** Selected component designed in CATIA V5.

**Table 2.** Total deformation of PBT reinforced with Aramid fibres.
Figure 4. Total deformation of PBT reinforced with aramid.

Table 3. shows the tabulated results of maximum and minimum stresses [29] acting in the component due to the force exerted. Figure 5. shows the portions where the stress is distributed in the PBT composite material reinforced with aramid fibres.

| Time [s] | Minimum [MPa] | Maximum [MPa] | Average [MPa] |
|----------|---------------|---------------|---------------|
| 1        | 1.5754        | 1.8746        | 0.532         |

Table 3. Equivalent stress of PBT reinforced with aramid
Figure 5. Equivalent stress for PBT reinforced with aramid.

In Table 4. are the present values of maximum and minimum values in terms of mm/mm; also, Figure 6. represents the strain formation in the model of PBT reinforced with aramid fibres.

Table 4. Equivalent elastic strain for PBT reinforced with aramid

| Time [s] | Minimum [mm/mm] | Maximum [mm/mm] | Average [mm/mm] |
|----------|-----------------|-----------------|-----------------|
| 1.       | 8.6394          | 2.5842          | 7.9239          |

Figure 6. Equivalent elastic strain for PBT reinforced with aramid
For PBT composite material reinforced with Cordenka the Youngs Modulus is calculated as 7435 MPa regarding the tensile test results. The results from the total deformation are identified and created in Table 5., for better understanding, Fig. 7. shows the total deformation for the material Cordenka.

**Table 5. Results of Total deformation for PBT-Cordenka**

| Time [s] | Minimum [mm] | Maximum [mm] | Average [mm] |
|----------|--------------|--------------|--------------|
| 1.       | 0            | 7.3424       | 1.7652       |

![Figure 7. Total deformation of PBT reinforced with Cordenka](image)

Table 6. presented the tabulated results of maximum and minimum stresses acting in the selected component due to the force exerted. Figure 8. illustrates the portions where the stress is distributed into the composite materials reinforced with Cordenka.

**Table 6. Equivalent stress for PBT reinforced with Cordenka**

| Time [s] | Minimum [MPa] | Maximum [MPa] | Average [MPa] |
|----------|---------------|---------------|---------------|
| 1.       | 1.5754        | 1.8746        | 0.532         |
Figure 8. Equivalent Stress for PBT reinforced with Cordenka

In Table 7. are the tabulated values of maximum and minimum values in terms of mm/mm. Figure 9. represents the strain formation in the model of PBT composite materials.

Table 7. Equivalent elastic strain for PBT reinforced with Cordenka.

| Time [s] | Minimum [mm/mm] | Maximum [mm/mm] | Average [mm/mm] |
|----------|-----------------|-----------------|-----------------|
| 1.       | 8.4978          | 2.5418          | 7.7939          |
4. Conclusion
It is generally known that the stresses in the bent region are high when installing the air duct. It is important to find a value that brings less overall deformation, stress and strain. A simulation in Ansys software was used for this finding. The composite material with selected types of fillers was used for this purpose to find the exact suitable material for use under various application conditions, such as stress, thermal conditions, pressure. Subsequently, a component was designed that withstood the general conditions. We found that the lowest composite materials PBT-Cordenka and PBT-Aramid, have stress values with the same stress value of 0.532 MPa. The conversion value of Cordenka is 0.23 mm and of aramid 0.26 mm. We achieve this lower value of the total deformation, and in this case, we can conclude that PBT-Cordenka is a more suitable type of composite material.

Acknowledgments
This paper is part of a project that has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No.723274.

http://www.lessthanwagonload.eu
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