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Effects of Bio-Particles on Mechanical and Quasi-Static Punch Shear Behaviors of Glass/Epoxy Composites

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Abstract

In this study, the effect of acorn powder reinforcement at different percentages on the mechanical and quasi-static penetration behavior of glass fiber reinforced composites was investigated. Reinforcement materials used are woven E-glass fiber and cleaned acorn micro powders. Powders were cleansed from impurities with a sodium hydroxide solution. Cleaned powders were mixed with resin by using a mechanical mixing method. Thereafter, resin mixture was applied to glass fibers with hand lay-up method and composite plate was produced by vacuum bag method. Quasi-static penetration tests were performed at room temperature as well as mechanical tests. While 1, 10 and 20 mm/min were selected as quasi-static penetration test speed, tension, compression and three point bending tests were selected as mechanical tests. Force and energy test results of quasi-static penetration tests of composites were compared with each other. Additionally, tensile, compressive and flexural strengths of the composites were investigated.

Keywords: Particle reinforced composites, bio-composites, glass fiber

1. Introduction

Commonly, composite materials are mostly made of petrochemical-based materials. However, these materials pose a serious environmental pollution problem due to their long dissolve time in nature (Bledzki and Jaszkiewicz, 2010). Therefore, bio-composites produced using biodegradable and renewable natural materials have been recently preferred (Kılınç et al., 2016). While forests are considered as the most important sources of natural materials, they are disappearing due to extreme usage of wood. For this reason, current investigations on the use of natural materials have focused on side product materials of forests and wood industry as a reinforcement material (Agayev and Özdemir, 2019). In various studies, natural products such as almond shell (Essabir et al., 2013), walnut shell (Zahedi et al., 2013), coconut shell (Bledzki et al., 2010) and vine stem (Kılınç et al., 2016) have been also used as fillers in manufacturing composite materials.

When the studies in the literature are examined, it is observed that different fiber and particle reinforcements are used rarely together as a reinforcement material. In these studies, it was concluded that different proportions of particle reinforcements positively affect the mechanical properties of fiber-reinforced composites (Singh and Rawat, 2018).

Recently, many researches have performed a study on composites with different material stacking sequences under various loading rates and boundary conditions. These researches concluded that laminated composite structures are sensitive to impact loadings of external loading conditions (Taghizahed et al., 2018). As a result, impact properties of glass/epoxy composites have been an important subject of many researches for recent years. The main goal in these researches is optimizing these materials for usage of different applications by understanding their characteristic properties and energy dissipating impact damage mechanisms (Erkendirici and Haque, 2012). Even though, many researches considered the impact loading as one of the most critical loading type. Due to its different damage responses, investigating low and high velocity impact are seen as a complicated task. Because of that using quasi-static punch shear test which has the same failure mechanisms, considered as a better option (Sadeghi and Pol, 2019). The researchers explained the ballistic behavior of composites as five stages in their study. These phases are listed as impact–contact and stress wave propagation, hydrostatic compression and local punch shear, shear plug formation under compression-shear, large deformation under tension-shear, and end of penetration. In addition, they stated that these stages could be examined better by using the force-deformation data obtained from the quasi-static punch shear test (Gama and Gillespie, 2008).

In this study, composite materials with both fiber and particle reinforcement were used. Acorn powder, which is a natural reinforcement material, was used as a particle reinforcement material at different ratios. Plain-woven laminates were also used as fiber reinforcement material. Because of the above reasons, quasi-static punch shear test responses of composites were investigated at different particle ratios, along with mechanical properties of composites.

2. Methodology

Particle and fiber reinforced composites were manufactured in this study. In the manufacturing of composites, 10-40 μm acorn powder was used as particle material and woven glass laminates with 500gr/m^2 were used as fiber material. F-1564 epoxy and F3487 hardener were used as the matrix material. The materials used in the manufacturing of composite panels are shown in Figure 1.

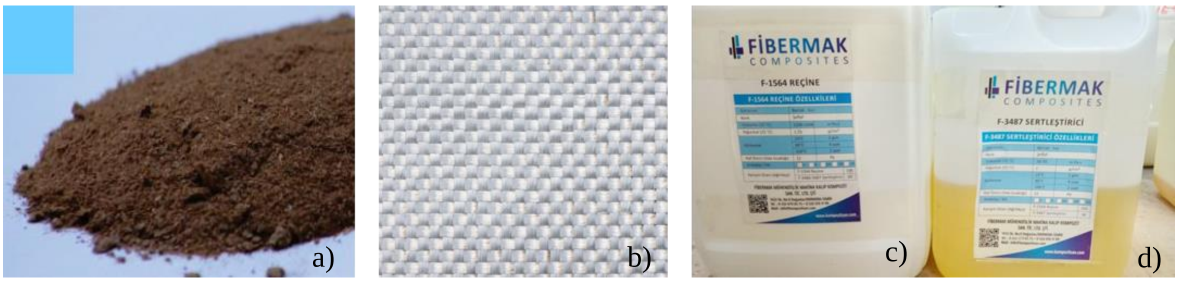

Figure 1. a) Acorn powder, b) woven glass fiber, c) F-1564 epoxy, d) F3487 hardener

Acorn powder was cleansed from impurities since it is a natural material. Grinded acorn powder was chemically treated in a 1.6mol 1-1 i sodium hydroxide aqueous solution for 48 hour. Hence, acorn powder was cleansed from contamination such as dust, corrosive organisms, natural residues and other materials. Purified acorn powder was left to dry for 96 hours before manufacturing of composite materials (Agayev and Ozdemir, 2019). Apart from this cleaning method, Ethylenediaminetetraacetic acid (EDTA) and polyethyleneimine (PEI) (Sigma–Aldrich, Seeze, Germany) can also be used for this process (Le Troedec et al., 2008). Acorn powder cleaning process are given in Figure 2.

Figure 2. Acorn powder cleaning process

Prepared acorn powder wase added to the respective epoxy resin and hardener and mixed mechanically at room temperature. The mixing ratio of hardener - epoxy resin is 1:3. In manufacturing of composites, hand lay-up method was preferred. The fiber content in the composite is 44% by weight. Firstly, the matrix-particle mixture were applied equally to each layer of composites in order to ensure homogeneous disturbance of particle. The vacuum tubes were connected to both ends of the structure in order to ensure balanced vacuum distribution in the later stages of the production process. After that, these composite laminates were vacuum bagged by a device from Dokuz Eylül University, as shown in Figure 3. Vacuum-bagged structure was left to curing for 8 hours at 80°C according to the instructions of matrix material.

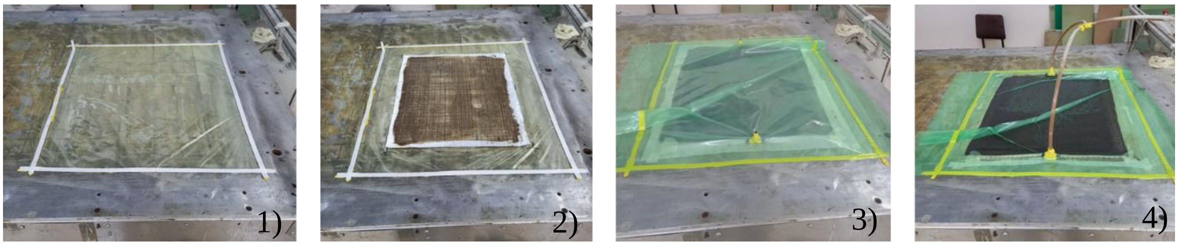

Figure 3. Composite plate manufacturing processes

After particle and fiber reinforced composite plates were manufactured, they were cut to the specimen sizes. Sizing process was performed by using a water refrigerated diamond blade Manufactured composite test specimens are given in Figure 4.

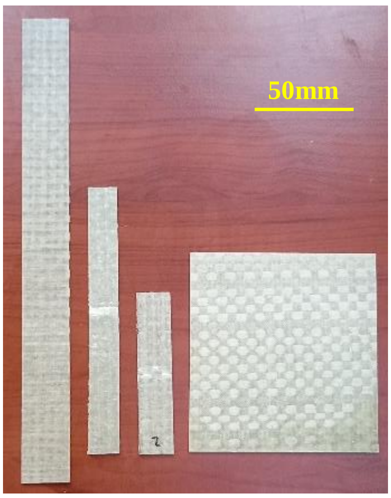

Figure 4. Manufactured composite test specimens

Tension, compression and three point bending tests were carried out at 1mm/min speed. The dimension of test specimens are 205x25 mm, 140x13 mm and 85x13 mm, respectively. In addition to mechanical tests, quasi-static punch-shear tests were also executed. Quasi-static punch-shear tests were carried out on 100x100 mm samples using a test apparatus with a clamp diameter of 76 mm. The cross head used in the quasi-static punch-shear tests is hemi-spherical shaped equipment with 12.7 mm head diameter. Quasi-static punch-shear tests were executed at 1, 10 and 20 mm/min cross head speed at room temperature. Tests were carried out at Shimadzu universal testing machine in Dokuz Eylül Mechanical Engineering Department. Each mechanical test was performed at least 5 times. The equipment that were used in the experiments are given in Figure 5.

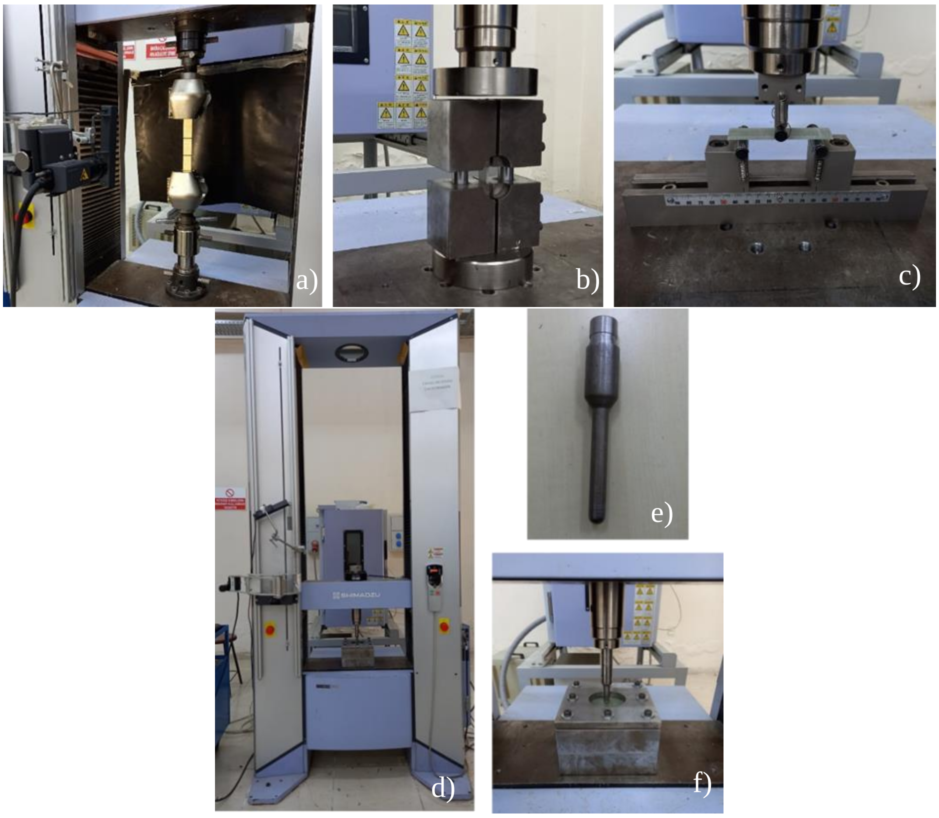

Figure 5. Experimental test setups of a) tensile, b) compression, c) three-point bending, d, e, f) quasi-static indentation tests

3. Results and Discussions

This research focuses on effect of acorn particle reinforcements in glass fiber reinforced composites. Tensile, three point bending and compression tests were performed in order to investigate the mechanical behavior of composites. Through mechanical tests, tensile strength, flexural strength and compressive strength of composites were determined along with tensile modulus and flexural modulus of composites. The mechanical properties of the composites are given in Figure 6. It can be observed from the figure that, tensile and compressive strength of composites increases until 2% particle ratio and then drops at 3% particle ratio. However, flexural strength, unlike tensile and compressive strength, shows a continuous increment trend with increasing the particle ratio. According to the Figure 6, while tensile modulus of composites starts to decrease after 1% particle ratio, flexural modulus of composites decreases after 2% particle reinforcement ratio.

Table 1. Mechanical strengths and modulus of acorn reinforcement specimens

	Tensile Strength (MPa)	Tensile Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (GPa)	Compressive Strength (MPa)
0%	334	18.6	402	16.4	209
1%	351	20.8	416	17.5	232
2%	373	19.5	423	17.6	247
3%	286	19.4	456	17.3	226

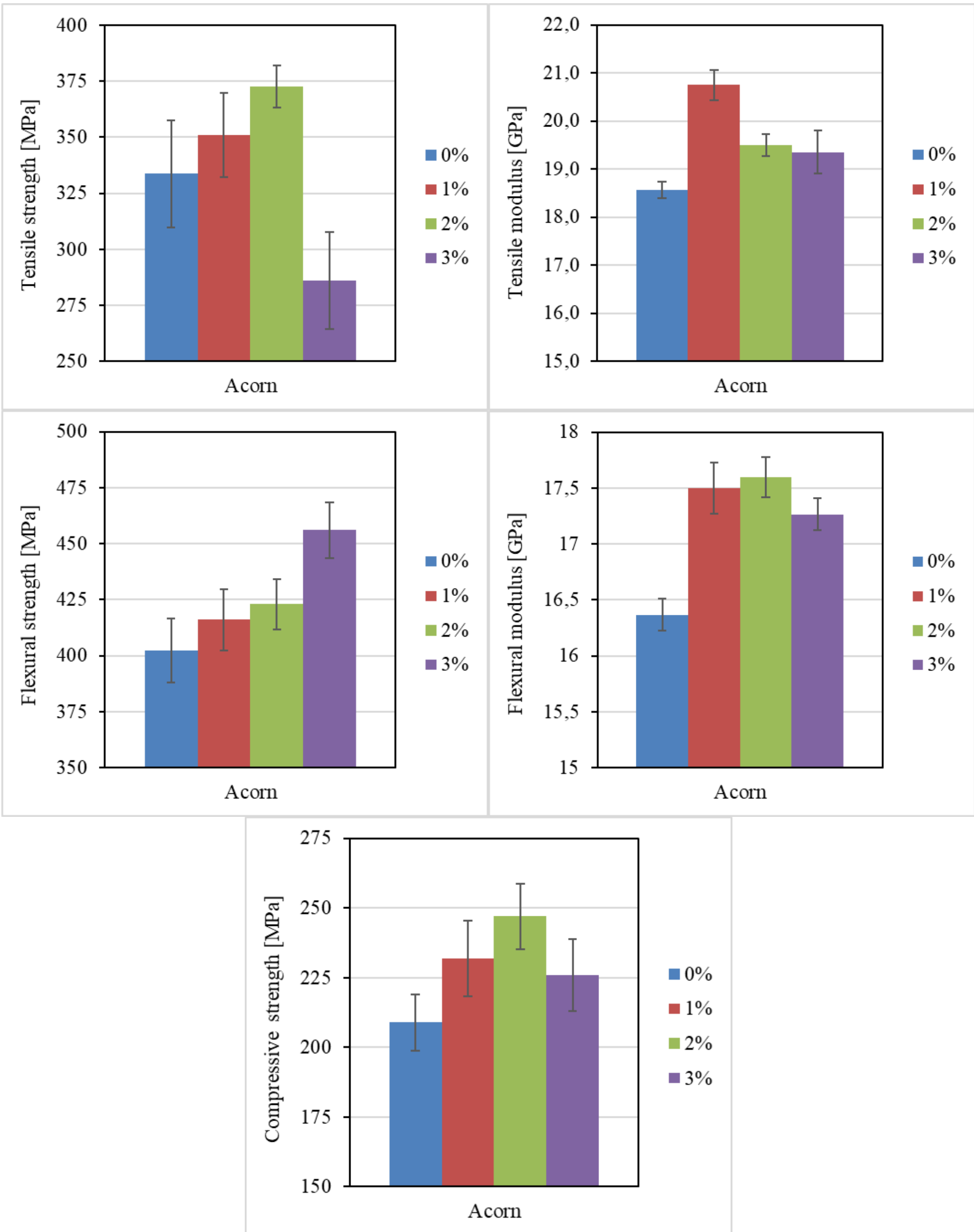

Figure 6. Mechanical strengths and mechanical modulus of acorn reinforcement specimens

Force – deformation curves obtained from the quasi-static punch-shear tests of 0%, 1%, 2% and 3% particle reinforced composites are shown in Figure 7. It can be observe from the figure that, curves increase linear tendency at the beginning of the test and initial parts of curves start separate further from each other along with increasing test speed. After initial area, curves turn to a nonlinear form because of permanent deformation damages. Curves continue to rising until plugging point. Force of composites decreases drastically after plugging point and stabilizes at a certain value after tip of cross-head move out from back of composite plate. After this point, friction create resistance effect against the cross-head.

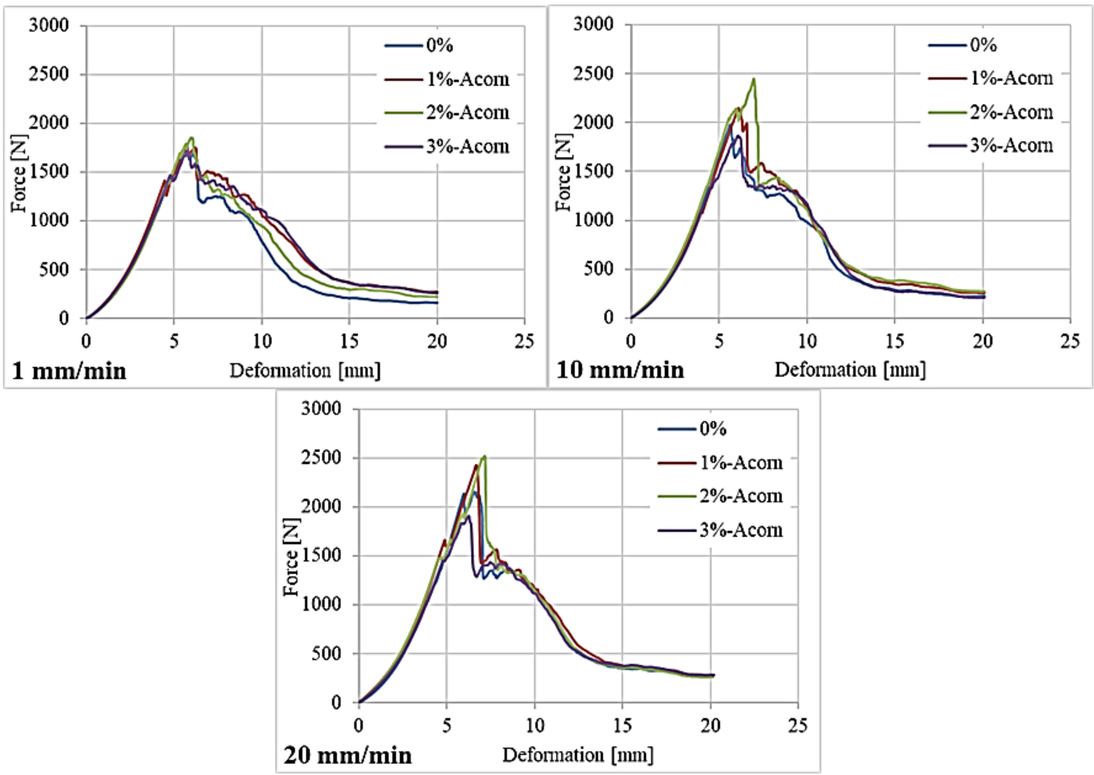

Figure 7. Force–Displacement curves of quasi-static punch-shear tests

In order to evaluate the quasi-static punch-shear strengths of particle-reinforced composites, maximum penetration force graphs and values are given in Table 2 and Figure 8. According to the Figure 8, maximum penetration forces of each composite group increases with increasing the test speed. Additionally, maximum penetration forces of composites gets higher values with higher particle reinforcement ratios until 2% particle ratio. Kılınc et al. determined that certain mechanical properties of composite, such as tensile strength, decrease when the ratio of the filler in the composite exceeds a certain value. They asserted that the reason for this situation was due to the poor distribution of the increased filler in the composite.

Table 2. Maximum penetration forces of quasi-static punch-shear tests

	0%	**1%**	**2%**	**3%**
1mm/min	1798	1845	1853	1755
10mm/min	2086	2178	2210	1892
20mm/min	2168	2267	2300	1943

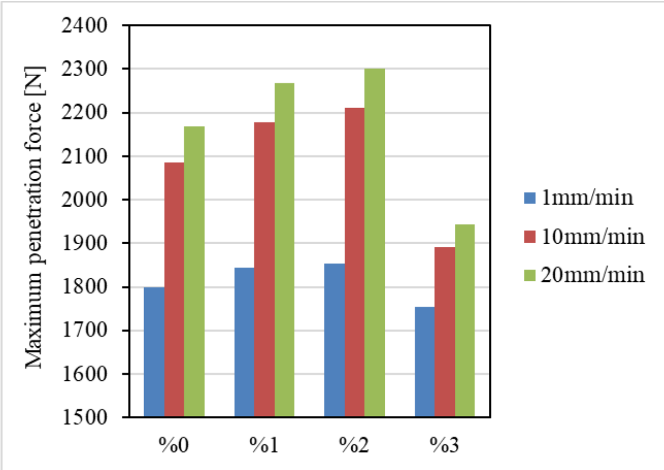

Figure 8. Maximum penetration forces of quasi-static punch-shear tests

Fiber plugging and rapture (maximum penetration force) point of composites is a critical point for quasi-static punch-shear tests (Öztoprak et al., 2022). Because of that, absorbed energy graphs and values of quasi-static punch-shear tests at fiber rapture point and at 20 mm deformation are given in Table 3 and Figure 9. It can be seen in Figure 9a that energy value of each composite group at fiber rapture point increases with increasing test speed. Furthermore, absorbed energy of composites at fiber rapture point gets higher values until 2% particle ratio. It can be seen in Table 3 and Figure 9b that absorbed energy value of each composite group increases when test speed increasing 1mm/min to 10mm/min. On the other hand, it starts to decrease when test speed increasing to 20mm/min.

Table 3. Absorbed energy value (J) of quasi-static punch-shear tests at fiber rapture point and 20mm deformation

Absorbed energy (J)		0%	1%	2%	3%
Rapture point	1mm/min	4.2	4.3	4.6	4.4
	10mm/min	5.5	5.9	6.6	4.8
	20mm/min	6.3	6.6	7.6	5.0
20mm	1mm/min	12.3	13.4	13.9	13.6
	10mm/min	15.2	15.3	15.4	14.8
	20mm/min	14.9	15.2	15.3	14.6

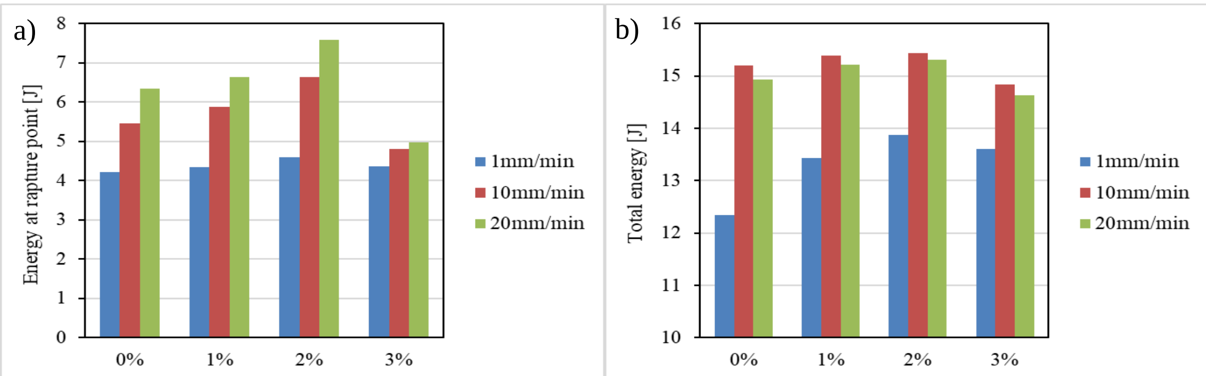

Figure 9. Absorbed energy of quasi-static punch-shear tests at a) fiber rapture point, b) 20 mm deformation

4. Conclusions

In this study, the effect of different amounts of acorn powder reinforcement on the mechanical and quasi-static penetration behavior of glass fiber reinforced composites was investigated experimentally. The quasi-static penetration tests were carried out at 1, 10 and 20 mm/min cross-head test speeds. The obtained conclusion can be summarized as:

- Tensile and compressive strengths of composites increase as the particle reinforcement increase up to 2%.
- Flexural strength of composites continuously increases with increasing particle ratio.
- Maximum penetration force of composites increases along with particle reinforcement up to 2% at quasi-static punch-shear tests.
- All absorbed energy values of composites decreases at 3% particle ratio.
- While the absorbed energy values obtained at fiber rapture point increase continuously with the increasing of test speed, absorbed energy value of composites at 20mm deformation decreases at 20mm/min test speed.

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Conflict of Interest

The authors declare no conflict of interest.

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