Material Usage of Oil-Palm Empty Fruit Bunch (EFB) in Polymer Composite Systems

Petr Valášek[1], Himsar Ambarita[2]
[1]Faculty of Engineering, Czech University of Life Sciences Prague. Kamýcká 129, 165 21, Prague. Czech Republic. E-mail: valasekp@tf.czu.cz
[2] Faculty of Engineering, Department of Mechanical Engineering, University of Sumatera Utara, Medan. Indonesia. himsar@gmail.com

This paper describes the material use of EFB biomass in the form of composite systems. It describes the tensile characteristics, hardness and wear resistance of polymeric disordered composites epoxy/EFB prepared by vacuum infusion. Electron microscopy was used to describe cellulose EFB fibers and their microstructures. The paper deals with a very simple material when the fibers were not separated from the EFB biomass - EFB biomass was used as it is produced by the processing line. The experiment describes composites with untreated EFB biomass and EFB biomass treated chemically with alkali - 6% aqueous NaOH. Due to the residue of the seed shells and clumps/fiber additions, the cracks initiate and the tensile characteristics decrease up to 46%. Although there have been no significant increases in observed characteristics, this material has some potential in terms of design or in the form of insulating material. The resulting properties could be enhanced by chemical treatment of the fibers, separation of fibers from the residues of the fruit and preferred fiber orientation.

Keywords: cellulose, tensile strength, renewable resources, natural fibres.

1 Introduction

Composite systems are materials composed of two and more phases [1-2]. In the field of composite systems, desirable substitution of primary sources by renewable natural resources has taken place in recent years. This substitution may be environmentally sensitive and may reduce the final cost of the material while maintaining the corresponding mechanical properties. [3-5]

During the processing of palm oil fruit, the empty fruit bunch (EFB) is produced, which is burned in a number of developing countries with negative influence on the local and global environment. Indonesia's typical mass production of palm oil is associated with the enormous burden of nature. The plantation of palm oil had to recede from the original vegetation, the processing lines are then another producer of ecological burdens. [6-8]

From the point of view of material flows, very interesting commodities, which can be processed meaningfully in a way that is not another environmental burden, arise during the processing of oil on processing lines. An example may be the empty fruit bunch (EFB), which accounts for more than 20% of waste produced in palm oil production [9]. EFB is often disposed of by unmanaged burning. Approximately more than 50 tons of dry matter in the form of fibrous biomass is flushed out by processing 1 ha of palm oil. Karina et al. [10] state that the tonne of palm oil produced is about 1.4 tonnes of EFB. Around 37.7 million tons of EFB is generated annually worldwide [11].

This biomass can be used, for example, to produce organic fertilizer or burned to produce electricity (in the form of pellets). However, there are cases where this biomass is burned uncontrollably near the processing line with a negative impact on the local as well as the global environment.

From a material engineering point of view, EFB is a good source of cellulosic fibers that can be used in composite systems [12-13].

The aim of the experiment is to describe the material utilization of EFB from the process of pressing palm oil fruit. There was no fiber separation in the experiment, but whole EFB biomass was used. The experiment aims to evaluate the advantages and disadvantages of polymeric material with filler in the form of EFB, especially from the point of view of tensile strength and the view of tribological characteristics. Conclusions can assist in the material utilization of this secondary raw material arising during palm oil extraction, as an opportunity for meaningful and environmental management of this commodity.

2 Material and Methods

EFB was obtained from an oil palm that was processed on a processing line - a mill in northern Sumatra, near Tebing Tinggi. This processing line pressurizes oil from palm oil, at the same time creating secondary biological raw materials - seed shells and EFB (see Fig. 1)

Fig. 1 *Line processing of oil palm fruits - North Sumatra - Indonesia*

The most important product of the processing line is palm oil, which accounts for approximately 90% of its profits, another commodity that is produced on the line are pellets for energy use, which are molded from EFB, these pellets make up about 10% of the profit. The line thus tries to take into account the environmental trends in this area. As a further possible potential, material utilization of EFB is seen (see Fig. 2). EFB fibers can be considered as plant cellulosic fibers with a cellulose content of 43% -65% and lignin from 13% -25% [14]. In the experiment, EFB biomass was used without chemical treatment and chemical treatment with alkalis - NaOH 6% aqueous solution, exposure time 12 h.

Fig. 2 *EFB biomass produced by the processing line*

EFB was removed from the line, then dried in an oven at 105 °C. From the EFB biomass, only large non-fibrous formations (whole fruit, distinct plums of fibers with a diameter in centimeters) were separated. Vacuum infusion was used to prepare test specimens. A two-component epoxy resin suitable for the Epoxy equivalent weight 180-196 g/mol Epoxy Index 0.51 to 0.56 mol/1000 g was used as the matrix. The parameters of the vacuum infusion were as follows: capacity 55 $l \cdot min^{-1}$, the absolute pressure of 100 mbar abs. In this way, plates of 200 x 300 x 4 mm were prepared from which abrasive water jets cut test specimens for abrasive and tensile strength according to the relevant standards (see Fig. 3). The fiber concentration corresponded to 30 wt%.

A stereoscopic microscope was used for the EFB image analysis, where the macrostructure composition of EFB biomass and fiber diameter was evaluated. The interfacial interaction, the microstructure of the EFB fibers and the fracture area evaluation were performed on a Tescan Mira 3 GXM electron microscope.

Testing bodies for experimental description of tensile strength were prepared in accordance with CSN EN ISO 527, tensile strength was tested according to CSN EN ISO 3167, hardness according to CSN EN ISO 2039-1 - ball-shaped indentor of 5 mm diameter, the strength was 961 N. The abrasion resistance of the epoxy/EFB boards was evaluated according to standard 23.208-79 (Wear resistance testing of materials by friction against loosely fixed abrasive particles) - this is three-point abrasion. Free abrasive particles of sand of a size 100 – 200 μm were strewed on a test sample of a dimension 30 x 30 x 4 mm to which rubber disc of a diameter 50 mm and a width 15 mm was pressed at the same time. 1000, 2000, 3000, 4000 turns were realized which corresponds to the rubber disc track of a length 157-628 m (1000-4000 turns). The rubber disc was pressed to the test sample surface by 1.58 kg. A peripheral speed of the rubber disc corresponded to 0.162 $m \cdot s^{-1}$. Resistance to abrasive wear was assessed by weight loss.

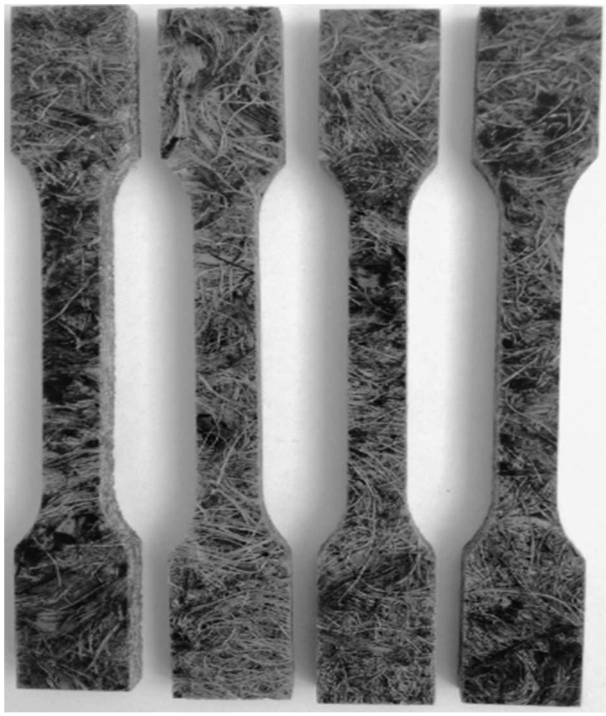

Fig. 3 *Testing samples for experimental assessment of tensile strength*

Measured data were statistically evaluated by ANOVA analysis and by T-test - significance level $\alpha = 0.05$. The zero hypothesis H_0 excludes that the monitored parameter had an effect on the observed quantity - there was no statistically verifiable change in the observed quantity ($p > 0.05$).

3 Results and discussion

EFB (Fig. 4 - a) was subjected to optical analysis on a stereoscopic microscope prior to inclusion. The EFB itself is composed of fibers (Figures 4-b), which pass into fruit and clumps/fiber clusters (Fig 4.-c) which are non-fibrous in nature.

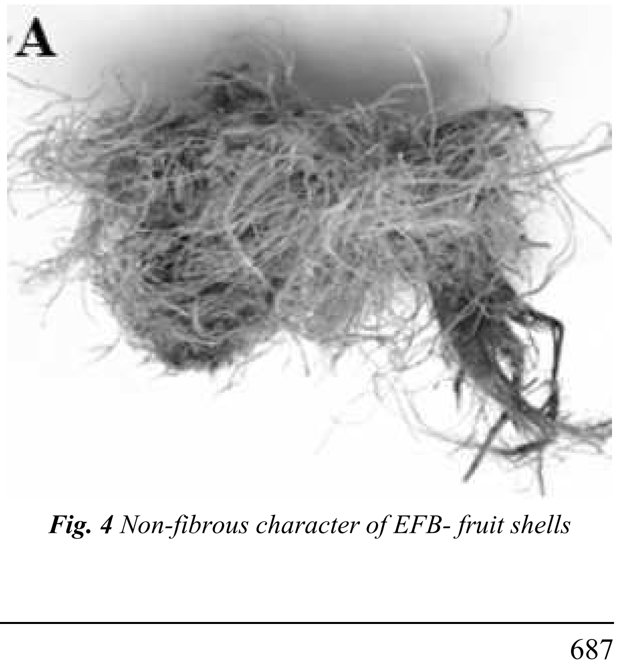

Fig. 4 *Non-fibrous character of EFB- fruit shells*

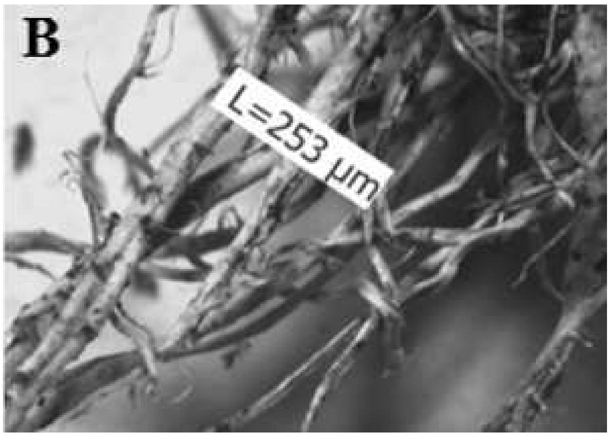

Fig. 5 *Non-fibrous character of EFB- clump/fiber clusters*

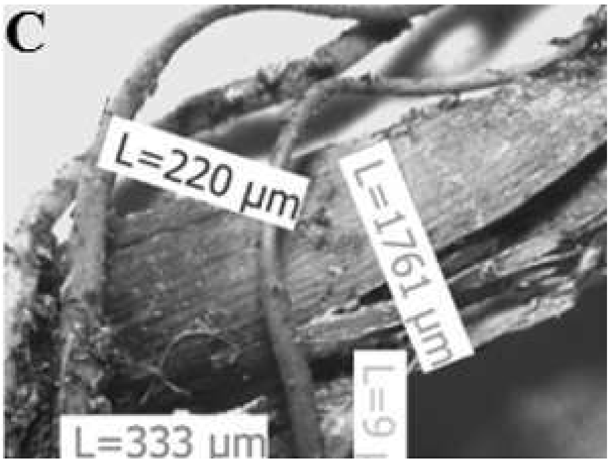

Fig. 6 *Non-fibrous character of EFB- detail*

Measurements have shown that the fibers have a very different diameter (477.2 ± 249.5 µm, see the histogram of Fig. 7) depending on the particular location of the fiber in the bundle. This disparate character affects the resulting mechanical characteristics of the fibers that are transmitted to the composite system itself.

Only fibers are evaluated in the histogram (Fig. 5), fiber clusters and non-fibrous formations having dimensions greater than 1 mm have not been taken into account. The length of the fibers was 89 ± 21 mm in diameter.

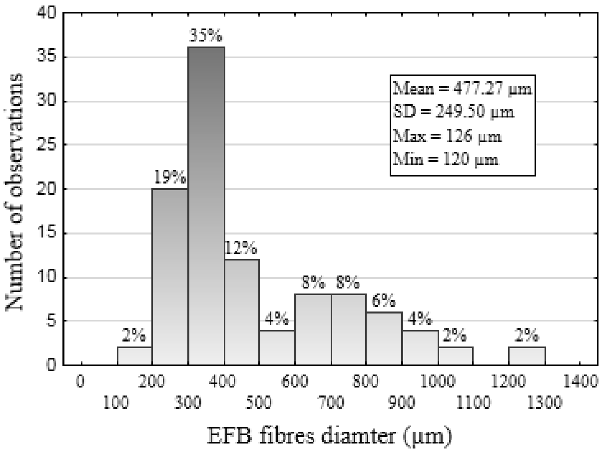

Fig. 7 *Histogram of the EFB fiber diameter (without clumps/additions of fibers and other non-fibrous formations)*

The microstructure of the EFB fiber is evident from Fig. 6. The fiber surface is an important aspect that affects the interfacial interaction of composite systems - the interaction between cellulose, hemicellulose, and lignin. The interaction between the polymer and natural fibers can be enhanced by the use of chemical treatments [12]. On the surface of EFB fibers are observable circular formations, called silica body, which are made of silicon and provide protection to the fibers by reducing microbial activities on the surface of the fibers (shown in Fig. 8).

Fig. 8 *Structure of EFB fiber surface*

EDS fiber surface analysis (see Fig. 9) was used to identify these structures, where the Si concentrations in these formations were confirmed. Silicon bodies have a circular shape with clearly recognizable spikes.

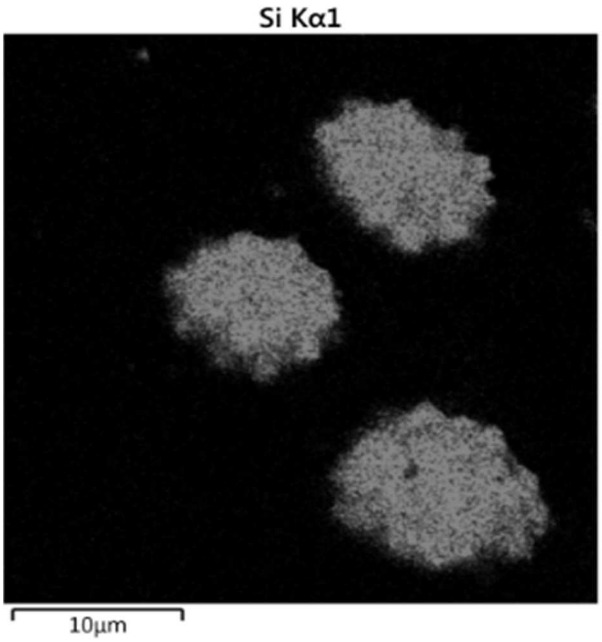

Fig. 9 *EDS analysis of Si presence in silicone body of EFB fibers*

.Microstructure of EFB fibers present in biomass is shown in Fig. 10. Individual elementary fibers are composed of primary and secondary cells, inside the elementary fiber there is a free space - lumen. This structure corresponds to the natural cellulose fibers described by a number of authors [13, 15].

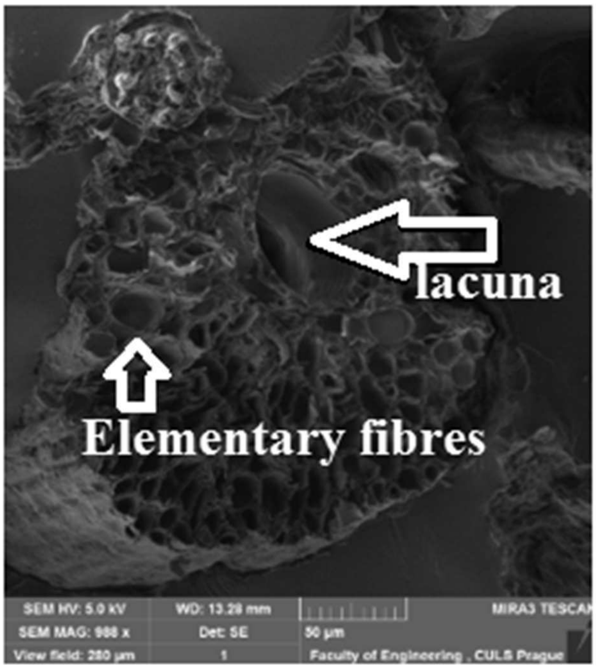

Fig. 10 *Microstructure of EFB fiber*

Tensile strength was influenced by the presence of non-fibrous formations, which reduced the strength characteristics of the system and the crack initiation occurred in the area of these bodies. The inclusion of EFB biomass resulted in a tensile strength drop of up to 19.9 MPa (see Fig. 11). There was no statistically significant difference in tensile strength between EFB biomass untreated and chemically modified - T-test: $p = 0.86$. Separation of fibers from non-fibrous formations should lead to optimization of the strength of composite systems.

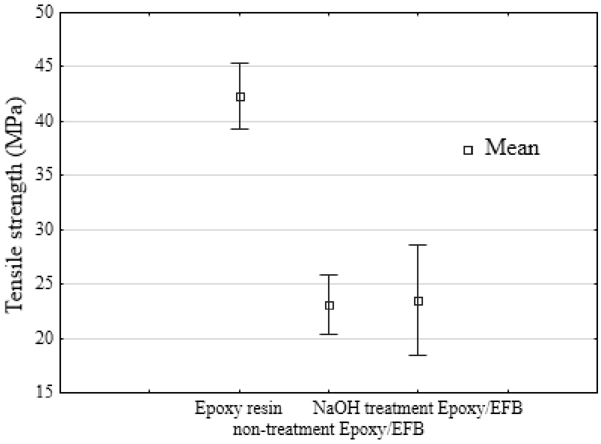

Fig. 11 *Tensile strength*

Better interaction of fibers with the epoxy matrix was observed after a chemical treatment of the fibers with an aqueous solution of NaOH (see Fig. 12 and Fig. 13), the resulting hardness values (see Fig. 14), however, were not influenced.

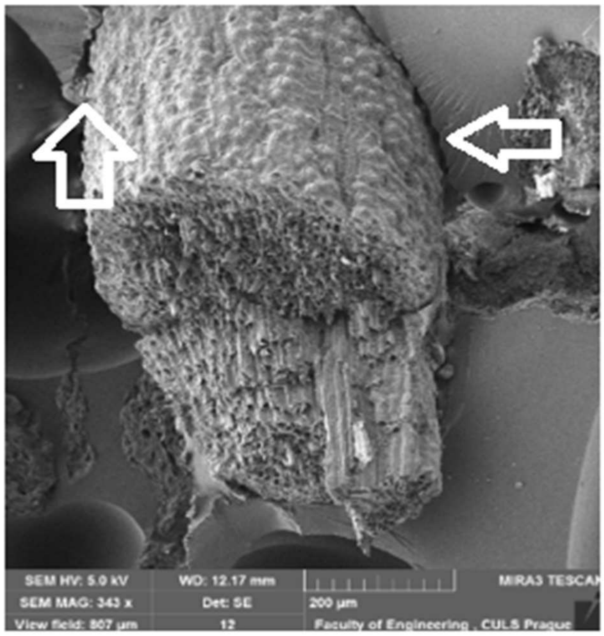

Fig. 12 *Incomplete wettability of EFB fibers without chemical treatment*

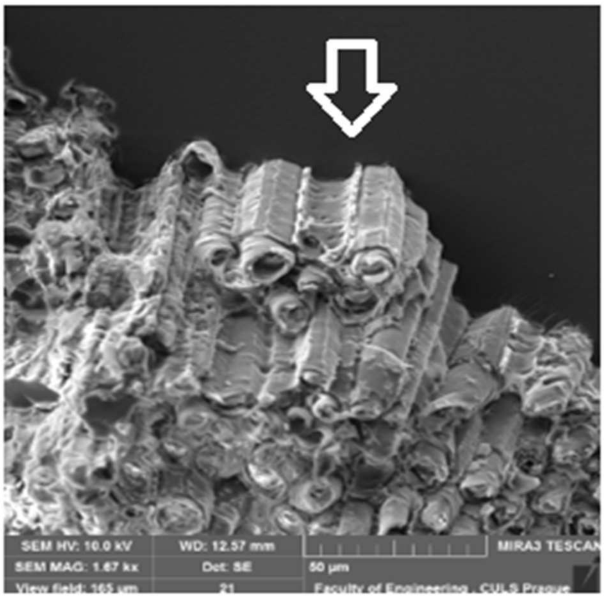

Fig. 13 *Good wettability after NaOH chemical treatment*

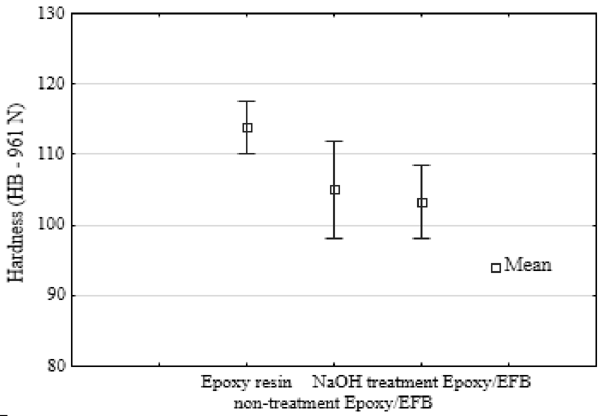

Fig. 14 *Hardness*

The results of abrasion resistance are shown in Fig. 15. The inclusion of the filler did not lead to a significant increase or decrease in wear resistance. Chemical treatment of fibers also has no demonstrable effect on the increase or decrease in weight loss. After 3000 revolutions (ie 628 m), the mass depletion of unfilled epoxy was recorded for 0.2829 ± 0.01549 g, 0.2971 ± 0.01783 g for Epoxy and EFB without treatment and 0.3036 ± 0.010969 g for Epoxy and EFB treated with NaOH.

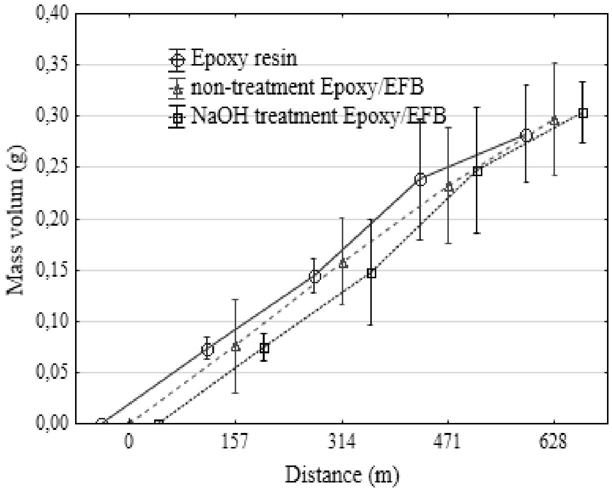

Fig. 15 *Resistance to three-body abrasive wear*

The paper deals with the possibility of using EFB biomass without separated non-fibrous parts. The separation of non-fibrous formations from EFB fibers is widely used according to many authors [4, 10, 13] in composite systems to optimize mechanical properties. Composite materiál are perspective materials of futute. Composite materiál are perspective materials of future. And their usage can be found in many applications. [16-18]

4 Conclusion

Inclusion of EFB biomass into polymeric materials creates an alternative material way of using secondary raw materials, which is inexpensive and environmentally sensitive. The plates thus prepared can be used, for example, as different insulating materials or can be used for surface treatments such as disagon materials. Describtion of the strength characteristics and wear resistance of such materials is important. The experimental results can be summarized as follows:

- The presence of EFB biomass did not significantly affect the ability of the resin to resist abrasion wear.
- The presence of EFB biomass led to a hardness drop of up to 13% and an increase in the variation coefficient of measurement.
- The inclusion of EFB biomass resulted in a decrease in tensile strength by up to 46.20% on average. The decrease was probably caused by the presence of non-fibrous formations, which are described by image analysis - fetal remnants and clusters/accretion of fibers larger than 1 mm in size.

Acknowledgement

The results were supported by the grant IGA TF 2017 (31140/1312/3113). The research was conducted thanks to the cooperation between the Department of Material Science and Manufacturing Technology of the Czech University of Life Sciences Prague (CULS), Faculty of Engineering and research center Sustainable Energy and Biomaterial Center of Excellence (SEB COE), Faculty of Engineering, University of Sumatera Utara., Indonesia.

References

[1] AFFATATO, S., RUGGIERO, A., MEROLA, M., LOGOZZO, S. (2017). Does metal transfer differ on retrieved Biolox®Delta composites femoral heads? Surface investigation on three Biolox®generations from a biotribological point of view, In: *Composites Part B: Engineering*, 113, pp. 164 – 173.

[2] RUGGIERO, A., MEROLA, M., CARLONE, P., ARCHODOULAKI, V.-M. (2015). Tribo-mechanical characterization of reinforced epoxy resin under dry and lubricated contact conditions. In: *Composites Part B: Engineering*, 79, pp. 595 – 603.

[3] ROSAMAH, E., HOSSAIN, M.S., ET AL. (2016). Properties enhancement using oil palm shell nanoparticles of fibers reinforced polyester hybrid composites. In: *Advanced Composite Materials*, pp. 1 – 14.

[4] VALÁŠEK, P., RUGGIERO, A., MÜLLER, M. (2017). Experimental description of strength and tribological characteristic of EFB oil palm fibres/epoxy composites with technologically undemanding preparation. In: *Composites Part B – Engineering*, Vol. 122, pp. 79 – 88.

[5] FOWLER, P.A., HUGHES, J. M. ELIAS, R.M. (2006). Biocomposites: technology, environmental credentials and market forces. In: *Journal of the Science of Food and Agriculture*, Vol. 86 (2006), pp.1781 – 1789.

[6] ROZMAN, H.D., TAY, G.S., KUMAR, R.N., ABUSAMAH, A., ISMAIL, H., MOHD. ISHAK Z.A. (2001). The effect of oil extraction of the oil palm empty fruit bunch on the mechanical properties of polypropylene-oil palm empty fruit bunch-glass fibre hybrid composites. In: *Polym.-Plast. Technol. Eng*, 40, pp. 103 – 115.

[7] PATERSON, R.R.M., KUMAR, L., TAYLOR, .S, LIMA, N. (2015) Future climate effects on suitability for growth of oil palms in Malaysia and Indonesia. In: *Scientific Reports*, n.14457.

[8] LIDU, S.R., MOHAMED, N., KLEMEŠ, J.J., VARBANOV, P.S., YUSUP, S. (2016). Evaluation of the energy saving opportunities for palm oil refining process: Sahabat Oil Products (SOP) in Lahad Datu. In: *Malaysia Clean Technologies and Environmental Policy*, 21, pp. 1 – 13.

[9] BADRI, K.H., OTHMAN, Z.B., RAZALI, I.M. (2005) Mechanical properties of poyurethane composites from oil palm resources. In: *Iranian Polymer Journal (English Edition)*, 14(5), pp. 441 – 448.

[10] KARINA, M., ONGGO, H., DAWAM ABDULLAH, A.H., SYAMPURWADI, A. (2008). Effect of oil palm empty fruit bunch fiber on the physical and mechanical properties of fiber glass reinforced polyester resin. In*: Journal of Biological Sciences*, 1, pp. 101 – 106.

[11] CUI, X., ZHAO, X., ZENG, J., LOH, S. K., CHOO, Y. M., LIU, D. (2014). Robust enzymatic hydrolysis of formiline-pretreated oil palm empty fruit bunches (EFB) for efficient conversion of polysaccharide to sugars and ethanol. In: *Bioresource Technology*, 166, pp. 584 – 591.

[12] PALAMAE, S., PALACHUM, W., CHISTI, Y., CHOORIT, W. (2014). Retention of hemicellulose during delignification of oil palm empty fruit bunch (EFB) fiber with peracetic acid and alkaline peroxide. In: *Biomass & Bioenergy*, 66, pp. 240 – 248.

[13] FARAH NADIA OMAR, SUHAIZA HANIM HANIPAHA ET AL. (2016). Micromechanical modelling of oil palm empty fruit bunch fibres containing silica bodies. In: *Journal of the mechanical behavior of biomedical materials*, 62, pp. 106 – 118.

[14] HASAMUDIN, W., SOOM, RM. (2002). Road making using oil palm fiber. Malaysian. In: Palm Oil Board Information Series, No. 171.

[15] YAN, L., CHOUW, N., HUANG, L., KASAL, B. (2016). Effect of alkali treatment on microstructure and mechanical properties of coir fibres, coir fibre reinforced-polymer composites and reinforced-cementitious composites. In: *Construction and Building Materials*, 112, pp. 168 – 182.

[16] VALÁŠEK, P., MÜLLER, M. (2012). Polymeric particle composites with filler saturated matrix. In: *Manufacturing Technology,* Vol. 12, No. 13, pp. 272 – 276.

[17] MÜLLER, M. CIDLINA, J.,DĚDIČOVÁ, K.., KROFOVÁ, A. Mechanical properties of polymeric composite based on aluminium microparticles. In: *Manufacturing technology*, Vol. 15, pp. 624 – 628.

[18] VALÁŠEK, P. (2016) Short sisal fibers reinforced epoxy resins: tensile strength. In: *Manufacturing Technology*, Vol. 16, pp. 637 – 641.

10.21062/ujep/161.2018/a/1213-2489/MT/18/4/686