Investigation of *pes planus* in Children between 6 and 12 Years and Sustainable Devices for Its Correction

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Introduction. The paediatric pes planus is a common orthopaedic problem described as a condition in which the longitudinal (lengthwise) and/or medial (crosswise) arches of the foot are dropped down or flat [1]. However, across the studies the different prevalence of pes planus among children is reported, ranging from 14 to 67% [1, 2]. The majority of children will grow out of their flat foot deformity, but pronounced pes planus needs treatment to prevent further injury. To alter the pattern of lower extremity joints' alignment and movement the orthoses and shoe inserts are widely prescribed [3]. The functions of these orthotic devices involve the distribution of plantar pressure, support of the body, the absorption of impact and postural adjustments [4]. Today's orthotics should combine contradictory properties: shock absorption and maximal energy return [4, 5], therefore traditional orthotic materials such as wood, aluminium, and leather have been largely replaced by high-performance composites [6]. The requirements of low weight, durability, size reduction, safety, and energy conservation have made fiber-reinforced plastic composites very attractive in this area [6]. The most devices worn today are made of carbon fiber [5]. However, it should be considered that many of these products are for personal use and worn limited period of time, i.e. after injury, during rehabilitation or by patients with changeable body dimensions (due to growth or change in body weight) as children. Thus the use of renewable materials in this field is gathering more and more attention [7].

The primary objective of this study was to determine the prevalence of pes planus in children between 6 and 12 years which are wearing orthotic device for a limited period of time, and secondary – to investigate the possibilities to use sustainable devices for its correction.

Methodics. A randomized group of 242 children between 6 to 12 years was involved in the investigation of the prevalence of pes planus. The plantographic foot imprint testing method was used for determination of foot morphology. The interpretation of the imprint was performed using a classification scheme consisting of 3 types of footprints; the footprint types I and II correspond to the different degree of low-arched foot and type III to the severe flat foot, the latter often encountered in pathological conditions.

The two types of materials intended for orthotic application for pes planus correction were chosen for this investigation, i.e. the synthetic carbon fiber and biodegradable natural (linen/wool) fiber reinforced poly(lactic acid) (PLA) matrix composites (materials characteristics are presented in Table 1).

Table 1. The characteristics of composites reinforcement and matrix polymer

	Woven fabric		**PLA matrix**
	Linen-wool	**Carbon fiber**	
Area density, g/m^2	170	160	–
Breaking force, cN/tex	10.3	21.0	–
Tensile strength, MPa	87.6	245.0	24.1
Elongation at break, %	10.6	0.9	3.1

The composite samples were subjected to low-energy impact test (according to the standard ISO 6603), dynamic mechanical analysis (DMA) and formability evaluation. For DMA the rectangular specimens of 60×10 mm^2 were subjected to three-point bending mode at a frequency of 1 Hz. The viscoelastic properties of composites i.e., the storage modulus *E'*, the loss modulus *E''*, and the mechanical loss factor *tan δ* (where *tan δ = E''/E'*) were evaluated in the temperature range from 25 to 180 °C at heating rate 1 °C/min. For formability evaluation the composite samples were subjected to complex (3D) shape orthotic device production using vacuum bag molding method and its quality assessment.

Results. The results of children foot morphology revealed that 62% of children have normal footprints (Fig. 1); i.e. the 36% of males and only 26% of females, which probably indicates the difference in growth potential of the foot between sexes also reported by S. Panagiotis et al. [8].

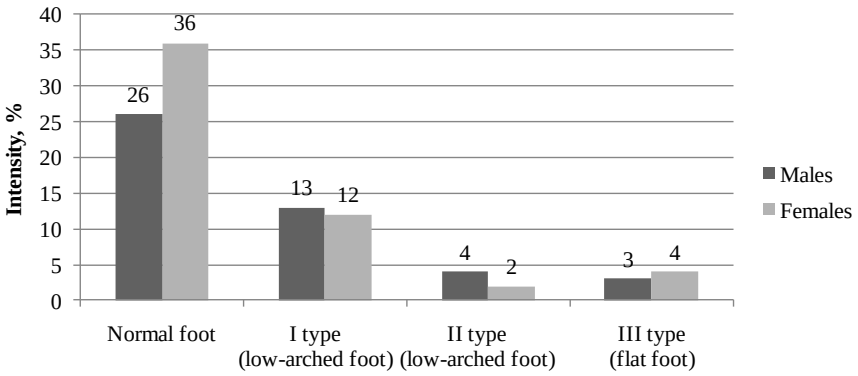


Fig. 1. The prevalence of pes planus in children between 6 and 12 years

The majority of the children with pes planus had I type footprint which corresponds to the slight degree of low-arched foot. However, 6 and 7% of children had the more pronounced II and III types of pes planus. This data has

agreement with the other research works that report 14% of pes planus [1], which in future could lead to pathological conditions.

The DMA plots of tested orthotic materials for pes planus correction are presented in Figure 2. The results have shown that natural fabric reinforced biocomposite has significantly lower storage modulus and indicates the higher flexibility and wearing comfort properties of this material in comparison with carbon fiber composite. It can be also seen that, on the contrary to storage modulus, there is only slight difference between the values of loss factor and indicates the vibration absorbing capacity (or damping capacity). The good impact absorbing properties of biocomposite were confirmed by the results of low-energy impact test; the carbon/PLA composite absorbed 5.47 J energy, whereas linen-wool/PLA – 5.10 J.

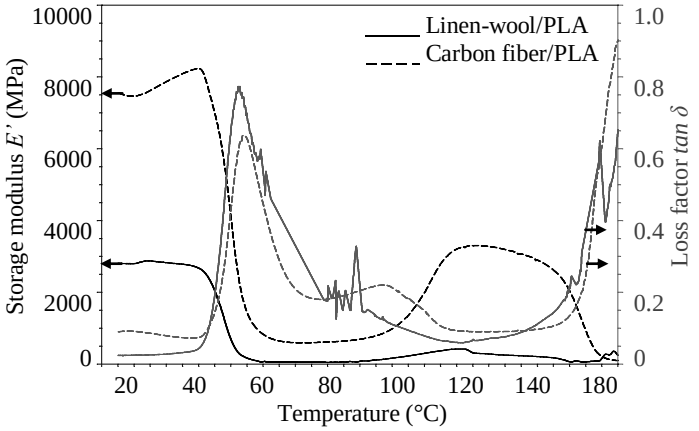
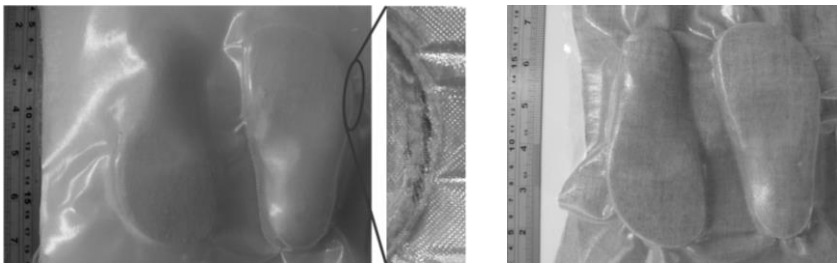


Fig. 2. The variations of storage modulus *E'* and loss factor *tan δ* of composites



a b

Fig. 3. The orthotic parts obtained during vacuum bag forming of synthetic (a) and natural (b) fabric reinforced composites

The results of material formability experiment are presented in Figure 3. The formability investigation has shown that due to poor extensibility of synthetic fabric during forming of several orthoses simultaneously the

insufficient depth or fibre breakage is obtained. Whereas the natural fabric reinforced composite orthoses had no defects.

Conclusions. It was determined that 13% of children have pronounced low-arched or flat foot problems and needs orthoses or shoe inserts to prevent further injury, where biodegradable natural fiber reinforced composites could be valuable alternative replacing non-degradable synthetic fiber composites. The biodegradable natural fabric reinforced composites not only have higher flexibility and wearing comfort properties, good impact absorbing properties in comparison with carbon fiber composites but also lower environmental impact.

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The aim of this study was to determine the prevalence of pes planus in children between 6 and 12 years which orthotic device are wearing limited period of time, and to investigate the sustainable materials for orthotic devices production. The study revealed that 13% of children have pronounced low-arched or flat foot problems. To prevent further injury the orthoses and shoe inserts could be prescribed, where natural fiber reinforced biocomposites could be valuable alternative to non-degradable synthetic fiber reinforced composites.