COMPOSITES WITH HEMP FIBRE WOVEN REINFORCEMENTS

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ABSTRACT

The research focuses on hemp yarn activity in the woven reinforcements, depending on the production method as well as production of reinforcement of natural yarns and thermoplastic yarns as a matrix in one woven product for the production of composites of building materials. The reinforcements of hemp yarns (100 tex), polypropylene yarns (100 tex) and polyethylene yarns (220 tex) were produced using a plain weaving technique on a craftsman's loom. The measurements of the fabric thickness and physical-mechanical properties of reinforcements were carried out according to ISO 5084:1996 and LVS EN ISO 13934-1-2001 standards. Fabric thickness of the hemp yarn reinforcement was 0.61-0.69 mm and density 91-100 g/m2. Tensile strength of the hemp reinforcement in the warp direction was 241 N-279 N and in the weft direction 249 N -302 N; tensile modulus- 218 MPa-271 MPa and 189 MPa-196 MPa. The Laboratory Press LP_S_50/SASTM) was used for the production of composites. The mechanical properties of the composite were established according to ISO 527-5:2009 standard and thickness swelling in water was conducted in accordance to EN 622-2: 2004 standard. Composite thickness depending on the reinforcement layers in the composites was from 0.34 mm to1.1mm; the density of the composites varied from 311 g/m2 to 1040 g/m.2 Tensile strength of the composites varied from 303 N (one layer) to 2019 N (five layers) and the elastic modulus of the same composites was 908 MPa and 1809MPa.

Key words: hemp yarns, woven reinforcements, thermoplastic matrix, composites

INTRODUCTION

Research on natural fibre composites has existed since the early 20th century, but it received more attention in the late 1980s. Composites, primarily glass but including natural reinforced composites are found in countless consumer products including boats, skis, agricultural machinery and cars (Dammer L., et al., 2013). The usage of textiles for the reinforcement of concrete is a flexible and efficient technology which can be used for repairing and strengthening existing structures, as well as for the production of load-bearing for façade constructions or non-load-bearing precast parts (Funkea H., et al., 2013; Hartig J et al., 2010; Hausding J, et.al., 2006; Hegger J., et al., 2008; Lepenies I., et al.; 2007).

Due to the worldwide emphasis on environmental awareness recent studies have pointed out hemp fibre composites as a promising option for applications that are currently using glass fibre composites and other materials with similar mechanical properties (Bernava A. et.al.; 2011; Bernava A., et.al., 2012; Manins. M. et.al., 2011; Westman M.P. et. al.,2010). The largest advantages of using natural fibres in composites are the cost of materials, their sustainability and density (Dammer L. et al., 2013).

The share of natural fibres in the fibre market has decreased over the last 20 years and in the year 2013 the amount of produced natural fibres was 33% of the fibre market. In 2012 the largest share of the European Union (EU) composites' market (total volume 150 000 t) of natural fibre 30 000 t, including hemp fibres 4 000 t were used for the automotive industry (De Vasconcellos D. S., et. al., 2012.). Jute and allied fibres gained interest as a reinforcing material in the composite industry to produce new and alternate building materials for low cost housing application, including: building panels, roofing sheets, boards' partitions, doors and windows, tiles etc. (Singh B., et. al., 2011). The addition of natural fibres to concrete was found helpful in producing cost-effective and sustainable building constructions and to improve various mechanical performances including flexural properties, impact resistance, fracture toughness, etc. even for glass and carbon fibres (Parveen S. et. al.,2012).

The interest in natural fiber-reinforced polymer composite materials in industrial applications is because they are renewable, cheaper, completely or partially recyclable (Manins M., et.al. 2015), they have low weight, good heat and sound insulation properties, and could offer an eco-friendly alternative to glass fibres (Bernava A. et.al., 2012).

Over the last decades, natural fibres grown as a raw material for industrial and household use have proved their popularity, economic viability and processing perspective in Latvia (Adamovics A., et. al. 2014; Strazds G., et.al. 2012).

Our pervious researches were focused on the comparison of the production method for woven reinforcement production and the mechanical properties. This research focuses on hemp yarn activity in woven reinforcements, depending on the production method, as well as the fabrication of the reinforcement of natural and thermoplastic fibre as a matrix in one woven product for production composites of building materials.

MATERIALS AND METHODS

Materials and Techniques

For the production of reinforcements the hemp yarns with a density of 100 tex, polypropylene (100 tex) and polyethylene (220 tex) yarns were used. Before weaving they were tested according to LVS EN ISO 5079:2001 standard (Table 1). For the production of the reinforcements an industrial loom СТБ-175 and a craftsman's loom in plain weaving technique was used.

Table 1

Parameters of the yarns used

	Designation	Yarn density, tex	Maximum load, N	Tensile extension, mm
Hemp	HA	100	15.4	17.3
Glass fibres	GF	136	97.4	4.1
Polypropylene	PP	100	-	-
Polyethylene	PE	220	-	-

The measurements of fabric thickness were carried out with the ATLASS thickness meter according to ISO 5084:1996 standards. The physical-mechanical properties of hemp and hybrid reinforcements in the warp direction were tested with the INSTRON dynamometer corresponding to LVS EN ISO 13934-1-2001 standard. The mechanical properties of the polypropylene and polyethylene yarns were not tested, because their task was to act as the composite matrix.

Composite Production and Testing

Before the production of the composite the reinforcements were held in a vacuum for 24h at a temperature of 25ºC.

For the production of laminate composites unidirectional lay- up method (Figure 1) with the change of the reinforcements warp direction (0°), the Laboratory Press LP_S_50/SASTM at a temperature of 190°C was used. The technological parameters for producing of composites were noted in table 3.

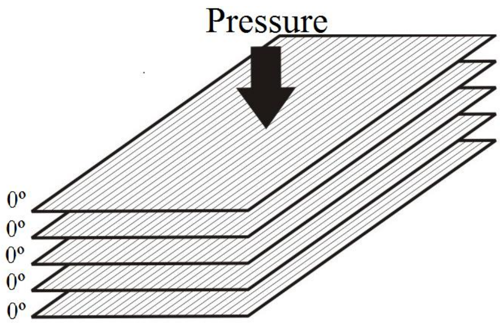
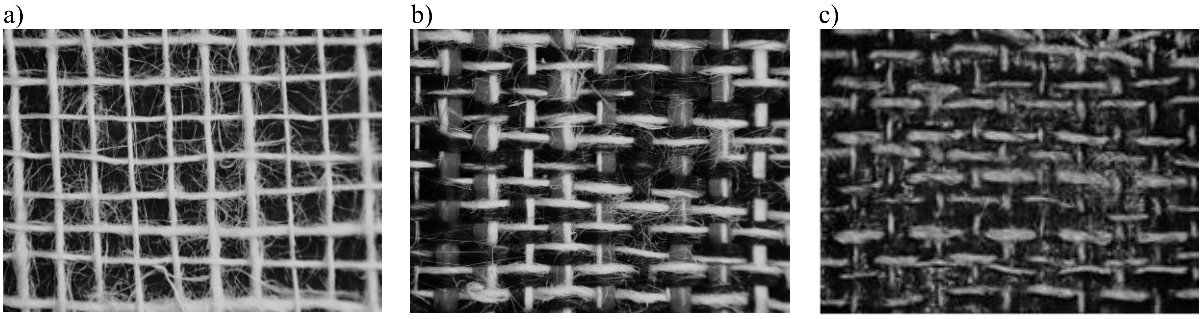


Figure1. Composites production method

The mechanical properties of the composite were established according to ISO 527-5:2009 standard.

The composites thickness swelling (TS) in water was conducted in accordance to EN 622-2: 2004 standard after 24, 48 and 72 hours.

a) b) c)



Woven reinforcement of hemp yarns | Woven reinforcement of hemp yarns and polypropylene yarns | Composite of hemp and polypropylene yarn reinforcement

Figure 2. Woven reinforcements and composite (size of sample 1.5* 2.0 cm)

RESULTS AND DISCUSSION

Woven reinforcements of hemp yarns were produced on a craftsman's and industrial loom while hybrid reinforcements of hemp and polypropylene or polyethylene yarns were produced on a craftsman's loom (Figure 2 A, B). The mechanical properties of the reinforcement of hemp yarns were compared since both looms have different thread feeders that affect the mechanical characteristics of the produced structure.

As can be seen in Table 2, the tensile strength in the warp direction is by 14% higher for the industrially made reinforcement, while in the weft direction it is higher for a handmade reinforcement (by 18%).

The tensile stress in both directions is higher for the handmade reinforcement by 3% (warp direction) and by 14% (weft direction). The tensile extension in both directions is lower (by 2%-4%) for the industrially made reinforcement. The tensile modulus in the warp direction is higher for the handmade reinforcement (by 20%), but in the weft direction for the industrially made reinforcement (by 14%).

The hybrid reinforcements with polypropylene or polyethylene yarns and glass fibres addition were not tested before the composite production, because the most prominent influence on the mechanical properties of reinforcements came from the polypropylene or polyethylene yarns, which act as the composite matrix. However, the influence of the glass fibre addition in reinforcements is insignificant due to the damage of the glass fibres during the weaving process.

Table 2

Reinforcement surface parameter, physical- mechanical properties

Reinforcement	Fabric thickness, mm	Surface density, g/m^2		Tensile strength, N	Tensile stress, MPa	Tensile Extension, %	Tensile Modulus, MPa
HA_industrial	0.61	91	Warp	279	6.7	2. 56	218
			Weft	249	7.5	3.44	196
HA_handmade	0.69	100	Warp	241	6.9	2. 60	271
			Weft	302	8.7	3.55	169
HA/PP	0.83	203		-	-	-	-
HA/PE	0.99	235		-	-	-	-

Table 3

The technological parameters for composite production and surface parameters

Fibre used, layer count		Pre heating contact	Pressing+ cooling	Composite thickness, mm	Surface density, g/m^2
C_1	HA/PP_1	10 sec	6 min	0.34	311
C_2	HA/PP_2	10 sec	6 min	0.59	608
C_3	HA/PP_3	10 sec	6 min	0.90	880
C_4	HA/PP_4	2 min	6 min	1.10	1040
C_5	HA/GF/PP_2	10 sec	6 min	0.59	480
C_6	HA/GF/PP_3	2 min	6 min	0.90	840
C_7	HA/GF/PP_5	10 sec	6 min	1.28	1220
C_8	HA/PE_1	7 min	5 min	0.26	213
C_9	HA/PE_2	7 min	5 min	0.47	424
C_10	HA/PE_3	7 min	5 min	0.67	692

Preheating time for the production of composites was from 10 sec to 10 min. The pressing + cooling time was about 5-6 min. The average thickness of the composites, depending on the reinforcement and the number of layers, varied from 0.26 to0.34 mm (1 layer composite); 0.47-0.59 mm (2 layers); 0.67-0.9 mm (3 layers); 1.1 mm (4 layers) and 1.28 mm (5layer composite). The composite's density for one layer composite varied from 213 to 311 g/m^2; for 2 layer composite - from 424 g/m^2 to 608g/m^2 ; for 3 layer composite from 692 g/m^2 to 880 g/m^2; for 4 layer composite 1 040 g/m^2 and 1 220 g/m^2 for 5 layer composite.

Composite's tensile strength (Figure 3; Table 4) is closely related to the number of reinforcement layers, regardless of the material and matrix used in the development of the composites. For one layer, the composite's tensile strength is 264 N- 303 N; for two layer composite it varies from 573 N to 652 N; for three layer composite - from 911 N to 999 N. For composites of 4 and 5 layers the tensile strength is respectively 1 459 N and 2 019 N. It means that with increasing the reinforcement layers, the increase of composite strength is by 29% (HA/PP composites) to 41% (HA/GF/PP composites). However, the influence of adding glass fibres in the reinforcement the warp direction is not significant. In the case of the elastic modulus (Figure 3; Table 4) of composites the number of layers does not always produce tangible influence. The difference between the elastic modulus of 2, 3 and 4 layer composites is 2%-7%.

The tensile stress (Table 4; Figure 4) increases by 6% for HA/GF/PP composites as well as about 17% with the increasing of HA/PP reinforcement layers in the composites. While the use of PE matrix gives an improvement of tensile stress of about 19% compared with PP matrix in the case of reinforcement of hemp yarns and 25% in the case of reinforcement of hemp and glass fibres. The lowest tensile extension of the composite (Table 3; Figure 5) is for the polypropylene matrix composite with 5 layer hemp/glass fibre yarn reinforcement (3.5%) and 2 layer hemp composite. For the composite of 1 layer reinforcement the tensile extension is about 3.9% (HA/PP_1) and 5.1% for one layer composite with the polyethylene matrix. The tensile extension 4.1% is for both matrix 3 layer composite, while 4.6% is for 4 layer composite with the polypropylene matrix.

Table 4

Physical - mechanical properties of composites

Composite		Tensile strength, N	Tensile extension, %	Tensile stress, MPa	Elastic modulus, MPa
C_1	HA/PP_1	303	3.93	35	908
C_2	HA/PP_2	599	3.53	40	1152
C_3	HA/PP_3	999	4.13	44	1075
C_4	HA/PP_4	1459	4.62	53	1148
C_5	HA/GF/PP_2	573	4.03	38	965
C_6	HA/GF/PP_3	925	4.10	41	1002
C_7	HA/GF/PP_5	2019	3.49	63	1809
C_8	HA/PE_1	264	5.19	42	814
C_9	HA/PE_2	652	4.32	55	1286
C_10	HA/PE_3	911	4.15	54	1310

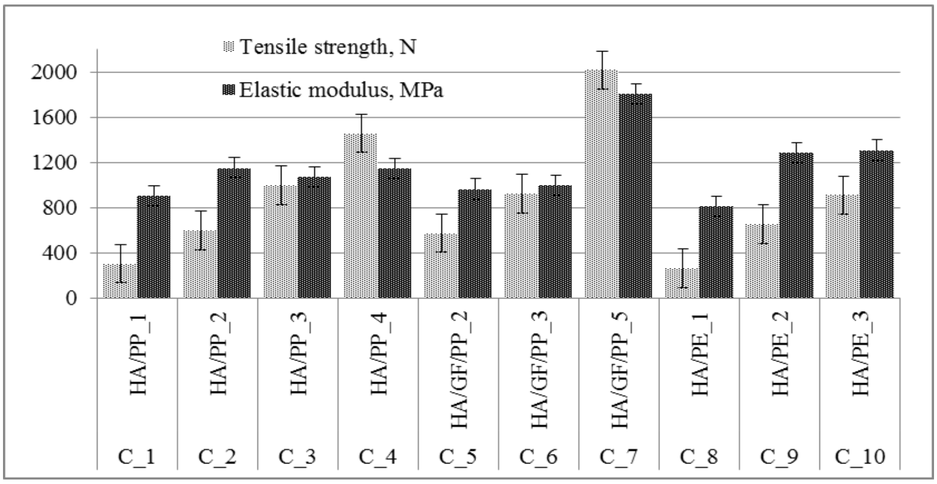


Figure 3. Composite Tensile Strength, N and Elastic Modulus, MPa

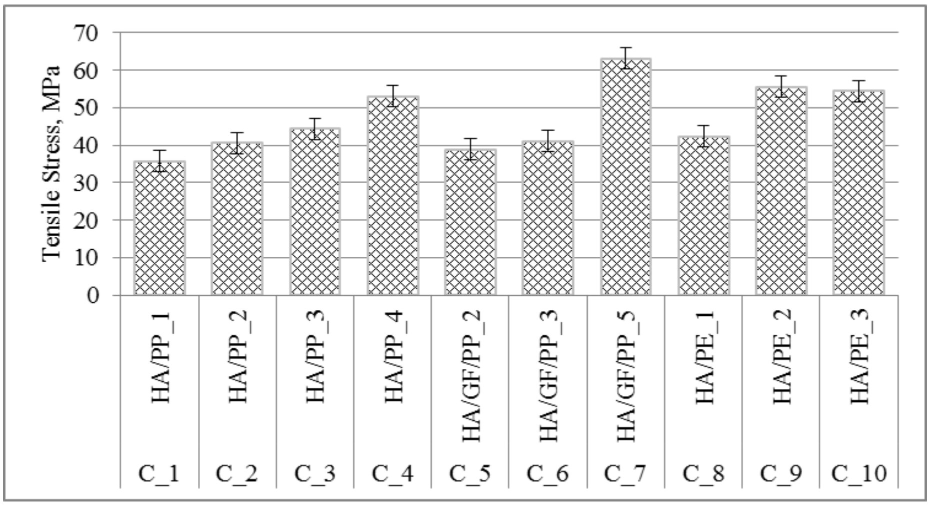


Figure 4. Composite Tensile Stress, MPa

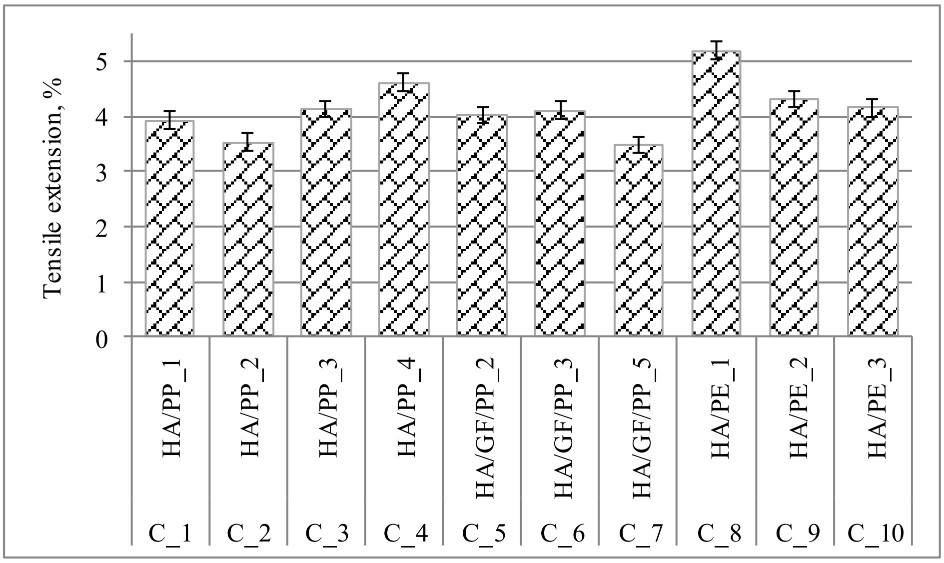


Figure 5. Composite tensile extensions, %

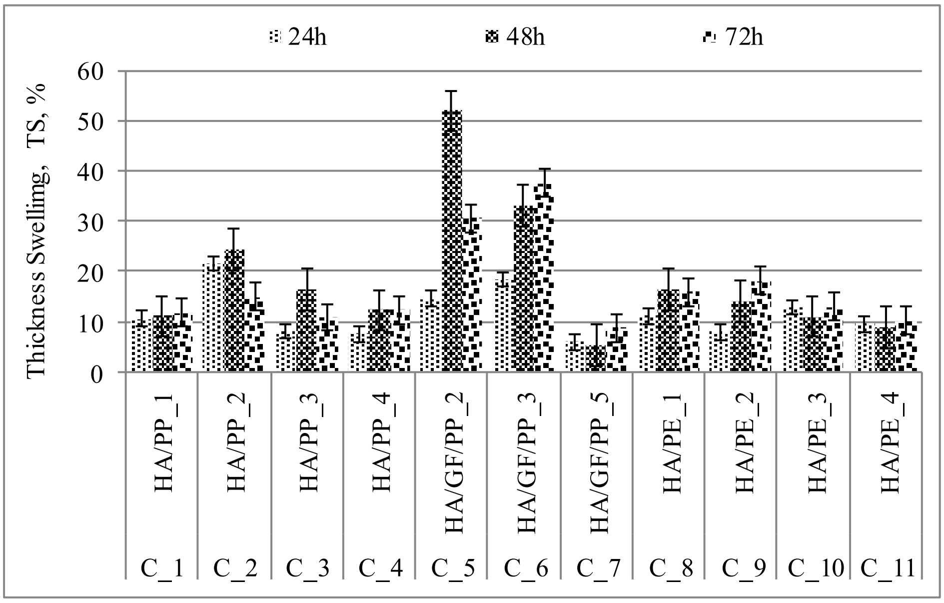


Figure 6. Composite thickness swelling TS, %

For one layer composite with the polypropylene matrix, thickness swelling (Figure 6) was 10.6%-11.8%; for 2 layer composite it was 14.9%-24.4%; for 3 layer composite thickness swelling was 8.1%-16.5% and for 4 layer composite it was 7.5%-12.3%. The most significant thickness swelling was observed for the composites with the reinforcement of polypropylene with glass fibres addition past 48h -33% - 52% and 30% -37% past 72h, while for 5 layer composite thickness swelling was 5.9%-8.7%. For one layer composite with the polyethylene matrix thickness swelling was 11.1%-16.5%; for 2 layer composite it was 7.9%-18.0% and for 3 layer composite 10.9%- 12.9% and 9.5% - 10.1% for 4 layer composite. From the results of the tests that were carried out the water absorption in the composites and thickness changes, it can be concluded that with the hemp yarn water uptake as well as by the hemp yarn damage with glass fibresin weaving process (C_6) a larger water uptake in the composite was observed.

CONCLUSION

2D woven structures depending on the application and composite processing were executed using the plain weaving technique.

Woven reinforcement production methods have a strong impact on mechanical properties. Such property as the tensile strength in the warp direction of the reinforcement is 14% higher for industrially made reinforcement, while in the weft direction it is 18% higher for a handmade reinforcement. The tensile stress is higher for handmade reinforcement on the weft direction (14%) and in the warp direction (3%) compared to the industrial made reinforcement. The tensile extension in both directions is lower for the industrial made reinforcement (2%- 4%). The tensile modulus in the warp direction is 20% higher for handmade reinforcement but in the weft direction for industrially made reinforcement - 14%.

For composites of hemp and polypropylene or polyethylene yarns the increase of composite tensile strength (19%-41%) and tensile stress (6%- 17%) depending on the number of reinforcement layers, compared to the previous number of layers was observed.

Composite tensile extension (3.5-5.1%) and elastic modulus (814.85N-1809.64N) depend on the reinforcement used , matrix properties as well as the method of composite production.

The changes in thickness from 8.74% (5 layer HA/GF composite) to 37.53% (3 layer HA/GF composite) by immersion in water for 72h were observed depending on the hemp yarn quality in the composite.

The composites of hemp and polypropylene or polyethylene yarns are applicable for wall covering panels, because this is a stable and low weight material with predictable fibre and matrix proportions in reinforcement and changeable composite design as well as properties.

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