BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Volumul 66 (70), Numărul 3, 2020
Secţia
CONSTRUCŢII. ARHITECTURĂ

SUSTAINABLE USE OF RED MUD SLURRY WASTE AS MIXTURE FOR IMPROVING THE MECHANICAL PROPERTIES OF WOOD PRODUCTS

BY

ANDREI LEIZERIUC[*]**, DORINA NICOLINA ISOPESCU, DRAGOȘ UNGUREANU, NICOLAE ȚĂRANU and RĂZVAN POLCOVNICU**

"Gheorghe Asachi" Technical University of Iaşi,
Faculty of Civil Engineering and Building Services, Iaşi, Romania

Received: August 11, 2020
Accepted for publication: August 27, 2020

Abstract. The bauxite residue, also referred as the red mud slurry is a waste generated from the Bayer manufacturing process. The disposal of red mud slurry can be made in liquid or solid phase. In both cases the waste disposals may leads to a severe environmental threat due to its microscopic particle size and high alkaline value. The recycling and reintegration of red mud slurry is currently a subject of interest for various research teams. This paper presents an efficient application for red mud slurry, *i.e.*, recycling the waste as a mixture for improving the mechanical properties of wood products. For this purpose, 15 wood specimens were prepared, treated with different mixtures of red mud slurry and tested in tension. The results were discussed and the particular gain in tensile strength were emphasized.

Keywords: red mud slurry; tensile strength of wood specimens; sustainability; recycle; waste reintegration.

[*]Corresponding author; *e-mail*: leizeriuc@yahoo.com

1. Introduction

Bauxite residue, or red mud slurry, is a waste produced from the alumina refining of the bauxite ore (the Bayer process). Usually, when the refining is done according to the conventional Bayer process, around 1 to 1.5 tonnes of red mud slurry results from the production of approximate 1 t of alumina (Zhang *et al*., 2011). The disposal of the red mud waste has a significant negative environmental impact due to its high pH value (between 10 to 13), and its large amount (Liu *et al*., 2007). In order to overcome this shortcoming of the Bayer manufacturing process, various methods of waste disposal and their potential impact on environment have been recently investigated around the world. Of these methods, the most common ones consist in landfill, storage in ponds and deep-sea dumping (Khairul *et al*., 2019). However, none of these methods implies the reintegration of the waste material in the economic circuit. Also, it is known that the red mud slurry comprises valuable elements, such as iron, titanium, rare earth elements and aluminium. These materials are also use in the construction industry, in particular in the mixtures that are deigned to increase the durability of wood and wood-based products (anti-aging, flame retardants, insecticides and antiseptics). The recycle of the red mud slurry waste and the recovery of rare earths and other valuable elements have been analysed and reviewed in several studies (Erçağ and Apak, 1997; Binnemans *et al*., 2015; Borra *et al*., 2016). Typically, the recovery methods are based on mineral subtraction using pyro-metallurgical, magnetic separation, and hydrometallurgical recovery techniques. In this frame, there is noticed a lack of studies focused on the direct utilization of the red mud slurry waste, without applying any metallurgical separation processes for the components. This paper presents an efficient application for red mud slurry, which consists in applying the waste (as it is) as a treatment for improving the mechanical properties of wood products.

Wood is a porous and fibrous structural tissue found in the stems and roots of trees. This structural tissue forms a heterogeneous, hygroscopic, cellular and anisotropic material with various applications in the construction industry (Florenta *et al*., 2017). The principal directions of wood (Fig. 1) are defined by three distinct axes: the tangential axis (tangent to the growth rings), the radial axis (perpendicular to both fibres direction and growth rings) and the longitudinal axis (parallel to the direction of the fibres), (Kretschmann, 2010; Isopescu and Stănilă, 2014). For this work, the tensile strengths (parallel to the fibre direction) of the wood specimens were experimentally determined after and before the red mud slurry mixtures were applied. The experimental program presented in this paper was developed at the Faculty of Civil Engineering and Building Services from Iaşi.

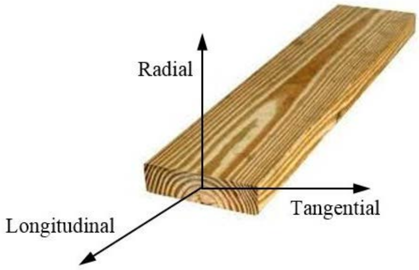


Fig. 1 − Principal directions of timber elements.

2. The Chemical Composition of the Red Mud Slurry Waste

The red mud slurry waste contains dangerous substances, with high alkalinity and highly soluble in water. Thus, the chemical analyses were carried out at a specialized chemical laboratory, which is accredited by TÜV for working with dangerous substances, waste and wastewater. The sampling, storage and transportation of the red mud slurry to the chemical analysis centre were carried out under the careful guidance of qualified laboratory personnel (Fig. 2). Also, the handling of the samples was made with appropriate protective equipment, and the resulting substances (after the chemical analysis was finished) were sorted and stored according to the internal waste management procedures of the laboratory. The chemical compounds which were identified for the red mud that was analysed in this work are listed in Table 1.

Table 1
The Chemical Compounds of the Red Mud Slurry

Sample type	Chemical compound	Quantity (%)
Red mud slurry sample burnt at 650ºC for 1.5 hours	Al_2O_3	20
	SiO_2	9.3
	P_2O_5	0.6
	SO_3	0.99
	Cl	1.0
	CaO	4.95
	TiO_2	3.40
	V_2O_5	0.16
	Cr_2O_3	0.19
	MnO	0.12
	Fe_2O_3	58.9
	Na_2O	<1
	K_2O	<1
	Total	**100**
	Calcination losses	**59.5**

Fig. 2 – Red mud slurry sample.

As can be observed, the Na_2O and NaOH amounts are shown cumulatively. This is due to the fact that Na_2O can be converted to NaOH by reaction with water. The identified particle sizes are, on average, between 2-100 μm. Therefore, the texture class is considered to be between mud and fine sand.

The density of the red mud slurry is 2.5 ± 0.7 g/cm^3. The average specific surface of the waste is 32.7 ± 12.7 m^2/g^1. These results correspond from the point of view of the physic-chemical analyses with the approximate particle size distribution and with the texture class specified above.

A significant part of the chemical compounds that were identified from the red mud samples are found in the composition of the usual treatments of wood elements (anti-aging, fire retardant, insecticide and antiseptic), as well as in the composition of treatments that are designed to improve the mechanical properties of wood products. For example, the silicon dioxide, which represents over 9% of the waste composition after calcination, is a common component for the commercially available chemical solutions used to improve the durability characteristics of timber structural elements (http://www.tratamente-lemn.ro/). This aspect validates the appropriateness of studies on the reintroduction of red mud waste into the economic circuit, through recycling and use in the composition of treatments for wooden products.

3. Experimental Set-up

The tensile strength of the wood material was determined by performing a series of experimental tests on standardized specimens (treated and untreated) that showed no visible natural defects.

The analysed wood was of soft essence (the category of conifers) and belongs to the spruce species. The harvesting was done in the cold season (November) and took place in the forested region in the southwest of Neamț County, Romania.

The geometries of the specimens (Fig. 3) were chosen according to the specifications given in the norm EN 408 (2004). The geometric features were checked by measuring each specimen with a digital vernier calliper, (Fig. 4*a*), and by weighing. The moisture content was determined using a HIT 3 - hammer type moisture meter for wood (Fig. 4*b*). During the experimental tests, the room temperature was maintained constant at 21°C and the relative air humidity was 58% (EN 408: 2004; Isopescu and Stănilă, 2014; Isopescu *et al.*, 2012). These values were measured using the Testo 435 digital thermo-hygrometer (Fig. 4*c*).

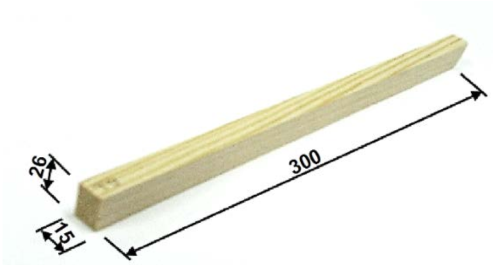
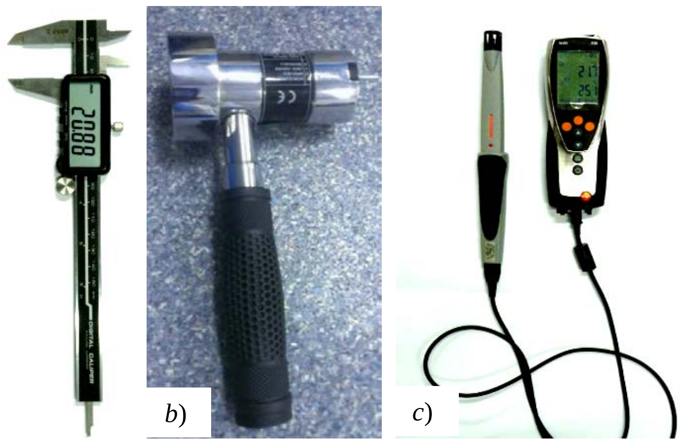


Fig. 3 − Specimens geometric configurations. Dimensions in mm.



a) *b*) *c*)

Fig. 4 – *a*) digital vernier calliper; *b*) HIT 3 - hammer type moisture meter for wood; *c*) Testo 435 digital thermo-hygrometer.

The treatment of the specimens in the red mud sludge solution was performed by immersion, inside a PVC container provided with a filling hole and an overflow hole (Fig. 5*a*). The sludge solution was heated up to 100°C using a 220 V electric hob (Fig. 5*b*). After all the treatments were finished, the specimens were left to cure in a metal vessel with a volume of 15 litres for 14 days (Fig. 5*c*).

Fig. 5 – *a*) PVC container provided with a filling hole and an overflow hole; *b*) 220 V electric hob; *c*) specimens left to cure in a metal vessel.

The tensile test was force controlled, at a 0.026 kN/s loading speed rate (EN 408: 2004). The experimental data were recorded on the dedicated data acquisition system of the WAW-600E universal machine (Fig. 6).

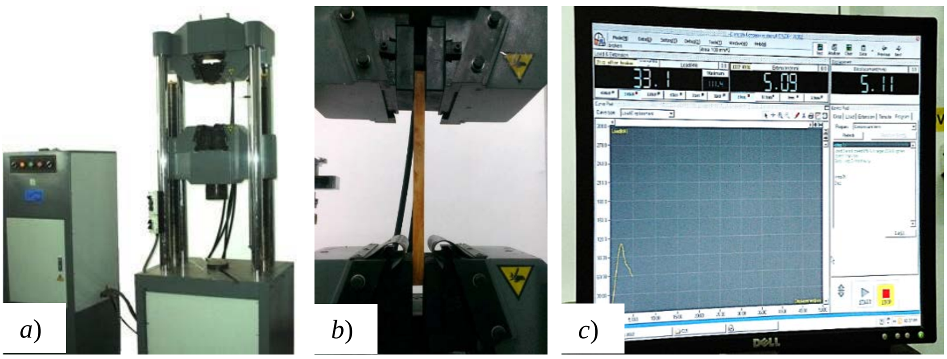


Fig. 6 – *a*) WAW-600E universal machine; *b*) specimen arrangement; *c*) data acquisition system.

4. Results and Discussion

The results obtained through the experimental tests are shown in Table 1. The tensile strength, parallel to the fibres, $f_{t,0}$ (Table 2), was determined according to the specifications of the standard SR EN 408: 2004, using Eq. (1).

$$f_{t,0} = \frac{F_{ult}}{A} \quad (1)$$

Where: F_{ult} – ultimate force in N; A – specimen cross sectional area in mm^2.

Table 2
Experimental Results

Specimen	Treatment with red mud slurry mixture	Cross section		Length (mm)	Humidity (%)	F_{ult} (kN)	$f_{t,0}$ (MPa)
		h (mm)	*b* (mm)				
1.1	*untreated*	26.63	15.83	302	8.20	9.90	23.48
1.2	*untreated*	26.40	15.71	305	9.50	4.43	10.68
1.3	*untreated*	26.15	15.65	303	9.20	9.77	23.87
2.1	*warmed up for 4h*	26.01	14.64	303	9.50	5.40	14.18
2.2	*warmed up for 4h*	26.06	15.14	302	7.50	7.92	20.07
2.3	*warmed up for 4h*	26.13	15.07	301	8.40	10.04	25.49
3.1	*warmed up for 8h*	26.16	14.64	300	7.70	7.57	19.76
3.2	*warmed up for 8h*	25.80	15.50	298	8.60	6.32	15.80
3.3	*warmed up for 8h*	26.46	15.70	302	11.10	6,9	16.60
4.1	*warmed up for 12h*	26.73	16.14	303	10.30	10.13	23.48
4.2	*warmed up for 12h*	26.60	15.60	302	8.70	12.57	30.29
4.3	*warmed up for 12h*	26.67	15.72	301	9.60	7.93	18.91
5.1	*warmed up for 24h*	26.15	15.40	302	11.20	10.96	27.21
5.2	*warmed up for 24h*	25.95	15.20	302	11.60	11.04	27.98
5.3	*warmed up for 24h*	26.45	15.10	301	12.50	7.94	19.88

The tensile strengths values correspond to the humidity of the specimens at the time of the test. According to the specifications of the Romanian standard SR EN 384 (2004), for the tensile strength, parallel to the wood fibres, no corrections are necessary. Therefore, the tensile strengths corresponding to the humidity of 12% are identical to those determined taking into account the humidity of the test pieces at the time of the test. The characteristics curves, force vs displacements obtained through the tensile tests of the specimens are presented in Figs. 7 - 10.

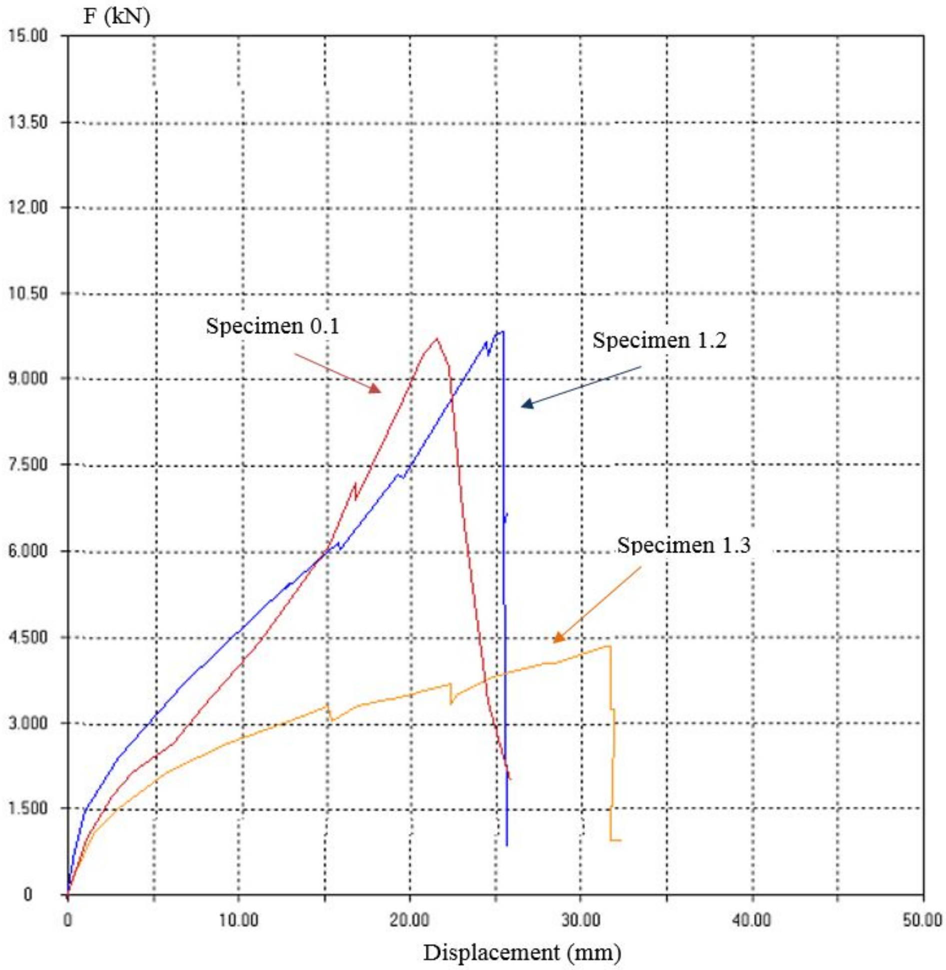


Fig. 7 − Force vs. displacement characteristic curves
for the untreated specimens.

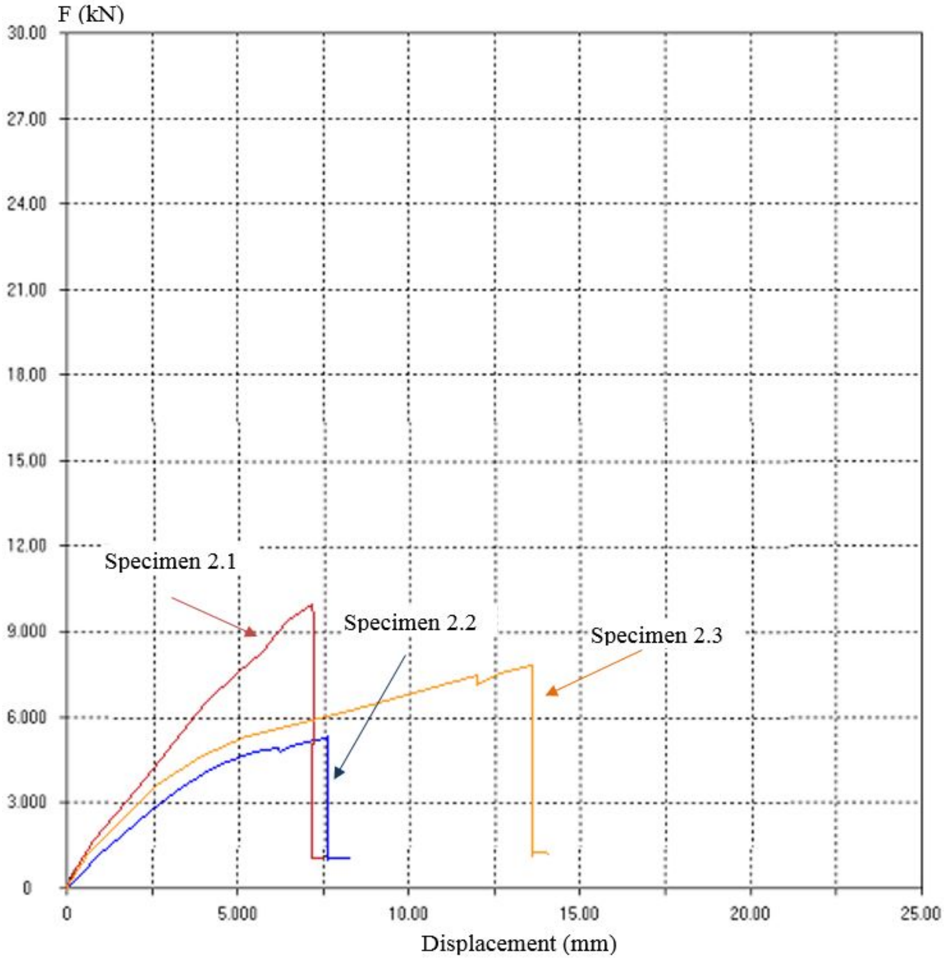


Fig. 8 − Force vs. displacement characteristic curves for the specimens warmed up in red mud slurry solution for 4 hours.

As it can be observed, the ultimate force and the tensile strength (Table 2, Figs. 7 – 9) corresponding to the specimens that were immersed and warmed up in the red mud slurry mixture for 4 and 8 hours, are similar to the ones determined for the untreated specimens. The mean ultimate force determined for the untreated specimens was 8.03 kN. The mean ultimate force determined for the specimens warmed up in red mud slurry mixture for 4 hours was 7.78 kN and for the specimens treated for 8 hours was 6.93 kN. Similarly, the mean tensile strength of the untreated specimens was 19.34 MPa, while for the specimens treated for 4 hours was 19.91 kN and for the specimens warmed up in the red mud mixture for 8 hours was 17.38 kN. Thus, it can be concluded that the treatments that consists in immersion and warmed up in red mud slurry mixture for 4 or 8 hours do not contribute to the enhancement of the tensile strength of wood specimens. Also, in this particular case, a slight diminish of the ultimate values of forces, displacements and tensile capabilities can be noticed.

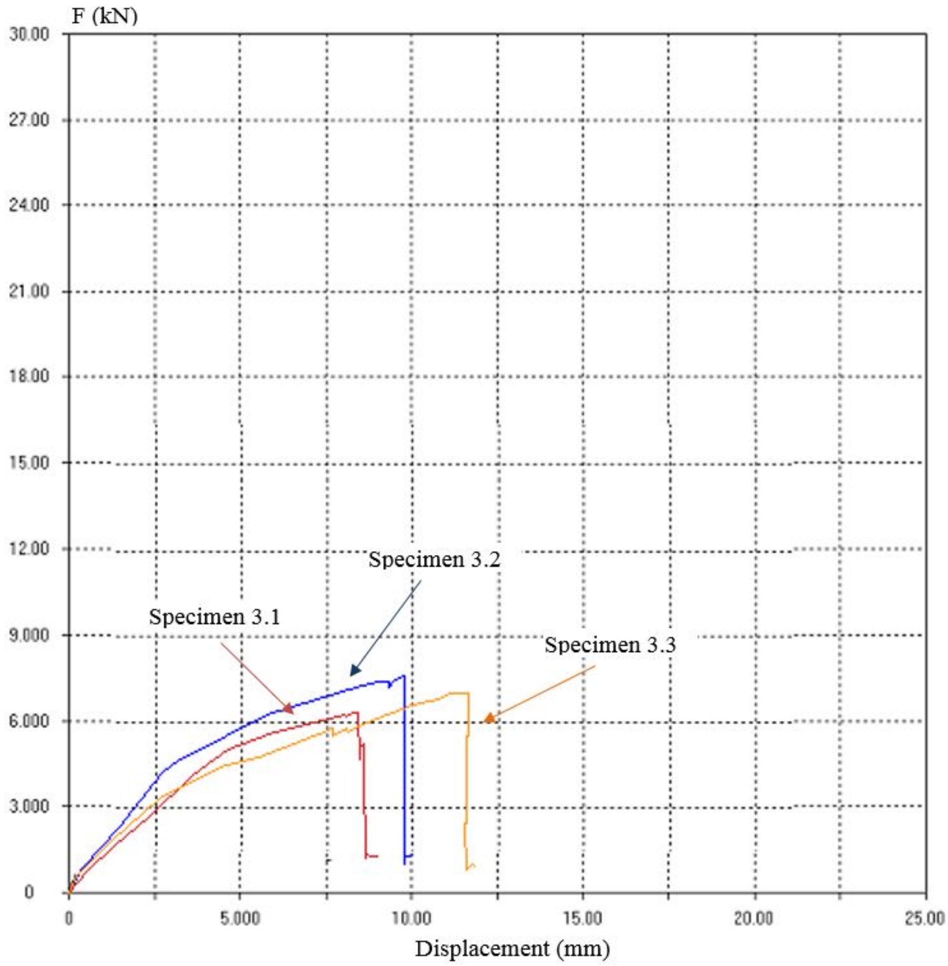


Fig. 9 − Force vs. displacement characteristic curves for the specimens warmed up in red mud slurry solution for 8 hours.

The mean ultimate forces and the mean tensile strengths of the specimens that were immersed and warmed up in red mud slurry mixture for 12 and 24 hours are higher than the ones determined for the untreated specimens. In particular, the mean ultimate force of the specimens that were treated for 12 hours (10.21 kN) is 21.35% higher compared to the mean value computed for the untreated specimens (8.03 kN). Similarly, the mean ultimate force of the specimens that were treated for 24 hours (9.98 kN) is 19.54% higher compared to the mean value computed for the untreated specimens (8.03 kN).

Also, the mean tensile strength of the specimens that were treated for 12 hours (24.23 kN) is 20.18% higher compared to the mean tensile strength computed for the untreated specimens (19.34 kN). Similarly, the mean tensile strength of the specimens that were treated for 24 hours (25.03 kN) is 22.73% higher compared to the mean tensile strength computed for the untreated specimens (8.03 kN).

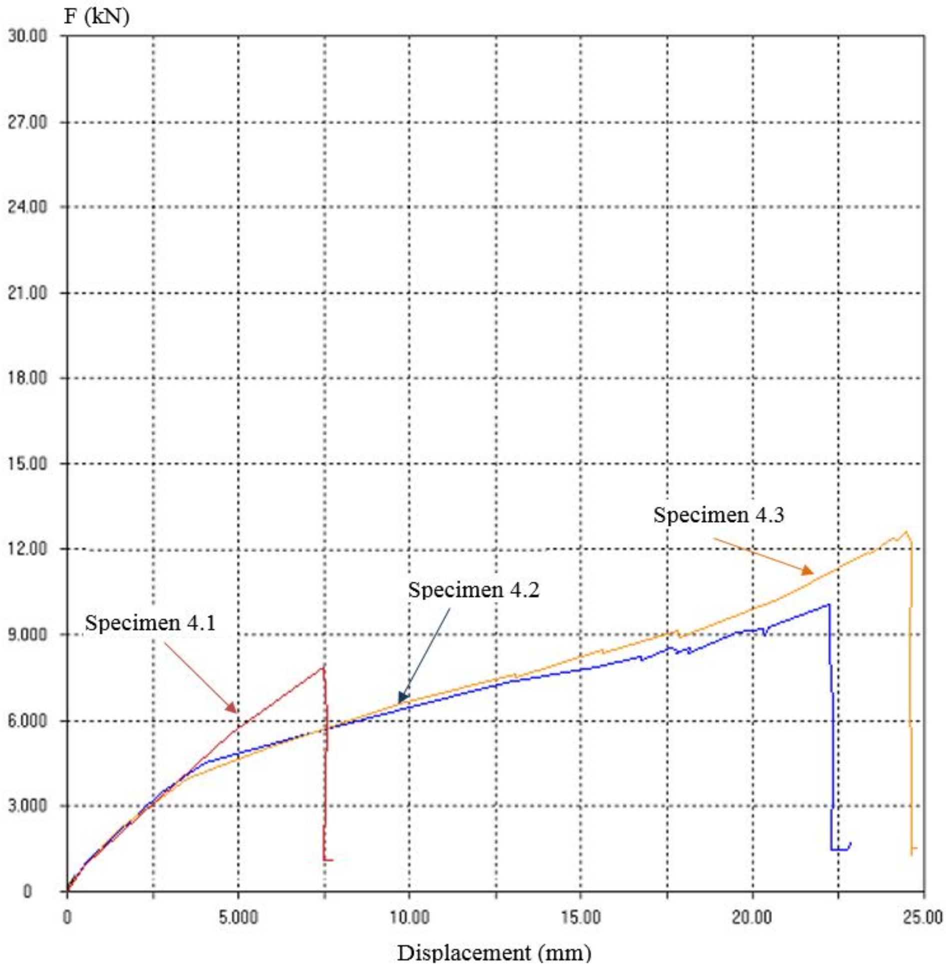


Fig. 10 − Force vs. displacement characteristic curves for the specimens warmed up in red mud slurry solution for 12 hours.

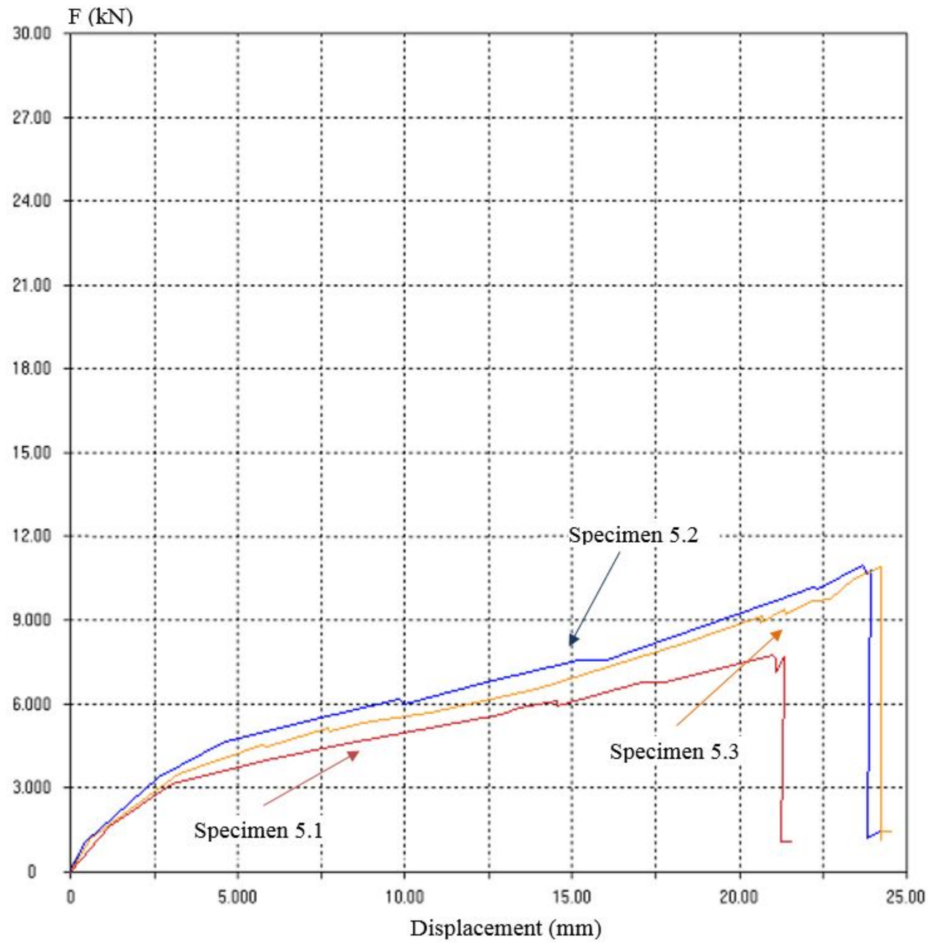


Fig. 11 – Force vs. displacement characteristic curves for the specimens warmed up in red mud slurry solution for 24 hours.

5. Conclusion

This paper presents the outcomes of an experimental study which focuses on the tensile properties of wood specimens that were treated by immersion and warmed up at 100°C in red mud slurry mixture. For this purpose, 15 wood specimens were prepared and tested by loading in tension. Twelve of these specimens were treated for different periods of time in red mud slurry mixture. The red mud waste was used as it is and no chemical or mineral subtraction methods were applied. Based on the experimental results that were presented in this paper, the following conclusions can be formulated:

- A significant part of the chemical compounds that were identified from the red mud samples are found in the composition of the usual treatments of wood elements (anti-aging, fire retardant, insecticide and antiseptic), as well as in the composition of treatments that are designed to improve the mechanical properties of wood products.
- The treatments that consists in immersion and warmed up in red mud slurry mixture for 4 or 8 hours do not contribute to the enhancement of the tensile strength of wood specimens. Also, in this particular case, a slight diminish of the ultimate values of forces, displacements and tensile capabilities can be noticed.
- The treatments that consists in immersion and warmed up in red mud slurry mixture for 12 and 24 hours contribute to the enhancement of the tensile strength of the wood specimens with 20.18% and 22.73%, respectively.
- The reintegration of the red mud waste material in the economic circuit, without applying any chemical or mineral subtraction methods is possible. In this frame, this waste material can be successfully used as treatment for enhancement the mechanical properties of wood elements. Also, this method contributes to the process of diminishing the large amounts of red mud waste, which are currently disposed in landfill, storage in ponds and deep-sea dumping.

REFERENCES

Binnemans K., Jones P.T., Blanpain B., Van Gerven T., Pontikes Y., *Towards Zero-Waste Valorisation of Rare-Earth-Containing Industrial Process Residues: A Critical Review*, J. Clean. Prod. 99, 17-38 (2015).

Borra C.R., Blanpain B., Pontikes Y., Binnemans K., Van Gerven T., *Recovery of Rare Earths and Other Valuable Metals from Bauxite Residue (Red Mud): A Review*, J. Sustain. Metal, 2, **4**, 365-386 (2016).

Erçağ E., Apak R., *Furnace Smelting and Extractive Metallurgy of Red Mud: Recovery of* TiO_2*,* Al_2O_3 *and Pig Iron*, J. Chem. Technol. Biotechnol. 70, **3**, 241-246 (1997).

Florenta I., Taranu N., Secu A., Entuc I-A., Scutaru M.C., Ungureanu D., *Evaluation of the Wood Strength Class Using the Experimental Approach*, Bul. Inst. Polit. Iaşi, **63(67)**, *2*, 121-132 (2017).

Isopescu D., Stănilă O., Astanei I., Corduban C., *Experimental Analysis of Wood Mechanical Properties from Bending, Tensile and Compression Tests*, Romanian J. of Materials, **42**, *2*, 204-219 (2012).

Isopescu D., Stănilă O., *Lemnul în construcţii: Îndrumar pentru lucrări de laborator*, Edit. Societăţii Academice “Matei-Teiu Botez”, Iaşi, 2014.

Khairul M.A., Zanganeh J., Moghtaderi B., *The Composition, Recycling and Utilisation of Bayer Red Mud*, Resources, Conservation & Recycling, 141, 483-498 (2019).

Kretschmann D.E., *Wood Handbook: Wood as an Engineering Material, Chapter 5 – Mechanical Properties of Wood*, Forest Products Laboratory, Madison, 2010.

Liu Y., Lin C., Wu Y., *Characterization of Red Mud Derived from a Combined Bayer Process and Bauxite Calcination Method*, J. Hazard. Mater. 146, **1**, 255-261 (2007).

Zhang R., Zheng S., Ma S., Zhang Y., *Recovery of Alumina and Alkali in Bayer Red Mud by the Formation of Andradite-Grossular Hydrogarnet in Hydrothermal Process*, J. Hazard. Mater. 189, **3**, 827-835 (2011).

*** Structural Timber, *Determination of Characteristic Values of Mechanical Properties and Density*, EN 384: 2004, CEN European Committee for Standardization, Brussels, 2004.

*** Timber Structures, *Timber and Glue Laminated Timber. Determination of Certain Physical and Mechanical Properties*, EN 408: 2004, CEN European Committee for Standardization, Brussels, 2004.

*** http://www.tratamente-lemn.ro/.

UTILIZARE SUSTENABILĂ A DEŞEURILOR DE NĂMOL ROŞU CA TRATAMENT PENTRU ÎMBUNĂTĂŢIREA PROPRIETĂŢILOR MECANICE ALE PRODUSELOR DIN LEMN

(Rezumat)

Reziduul de bauxită, denumit şi nămol roşu, este un deşeu generat din procesul de fabricaţie Bayer. Depozitarea nămolului roşu poate fi făcută în fază lichidă sau solidă. În ambele cazuri, depozitarea deşeurilor poate constitui o problemă gravă pentru mediu, datorită dimensiunii microscopice a particulelor şi a valorii alcaline ridicate. Reciclarea şi reintegrarea nămolului roşu este în prezent un subiect de interes pentru diferite echipe de cercetare. Această lucrare prezintă o reutilizare eficientă pentru nămolul roşu, care constă în reciclarea deşeurilor sub forma unui tratament pentru îmbunătăţirea proprietăţilor mecanice ale produselor din lemn. În acest scop, au fost pregătite 15 epruvete de lemn, tratate cu diferite amestecuri de nămol roşu şi testate la tracţiune. Rezultatele au fost discutate şi s-a subliniat creşterea în rezistenţa la tracţiune.