International Journal of Material Science & Engineering– IJMSE
Volume 1 : Issue 3 [ISSN 2374 – 149X]
Publication Date : 30 September, 2014

Study of the influence of wood aggregates on sand mortar extrudability

[J.G. Ndong Engone, Zhi Xing, Chafika Djelal, Yannick Vanhove, Hassina Kada]

Abstract: **The aim of this paper is to characterize the influence of wood sawdust and fibers on the extrusion behavior of a material with a cement matrix at various substitution levels of sand by wood aggregate. A study of the slump of extruded mixtures highlights the fluidity of these replacement mixtures. For the case of sawdust, the extrusion force recorded during testing indicates that the mixtures serve to reduce the necessary extrusion force. This extrusion behavior is not the same in the case of mortar fibers.**

Keywords: ***Waste, Recycling, Wood mortar, Rheology, Extrusion***

I. Introduction

The need to reuse waste generated by the wood industry has led France's Nord-Pas de Calais Region to set up a regionally-sponsored Wood research action program. One of this objectives project consists of producing new composite concrete-wood materials able to compete with and provide an alternative to well-known conventional building materials. The emphasis here is to develop a shaping process by means of extruding blocks of composite products containing regional wood species.

Extrudable cement matrix materials have become widespread over the past 20 years. Bresson [1] and Shao [2] demonstrated that the type of components can significantly influence the rheological behavior of a mix, which in turn modifies its behavior at the time of extrusion. The quantity of solid volumetric fractions (sands, gravel) of a cement matrix material also influences it extrudability [3, 4], with this influence related to the abrasive nature of the given solid fraction. To be extrudable, a material must be both plastic, in order to flow through the body of the extruder and fill the die, and sufficiently stiff to prevent deformations after exiting the die [5]. Nonetheless, obtaining a material whose physical state corresponds to that defined by Kuder [5] (semi-stiff material) remains a highly complex operation due to the heterogeneity of cement matrix materials. The inclusion of wood particles in these materials may further complicate the generation of a semi-rigid material. This study develops an understanding of the effect of such particles on the rheology of a cement material through use of a sand mortar, whose composition resembles that of a standardized mortar. This mix design was optimized by varying the paste (cement + water) volume in order to derive an extrudable material that will serve as a reference before adding wood aggregates.

J.G. Ndong Engone, Zhi Hing, Chafika Djelal, Yannick Vanhove, H. Kada
Laboratoire LGCgE / Université d'Artois.

II. Methods and equipment

A. *Methods*

To determine the influence of wood aggregates on sand mortar extrudability, a standardized mix design (according to Standard EN 196-1) was selected and optimized so as to yield a material capable of retaining its shape after leaving the die. This optimized mix design was then taken as the reference. The sand was replaced by two types of wood aggregates. The rheometers currently available on the market are limited to materials with a slump of no less than 100-mm. Rheological measurements were recorded with an Abrams cone, and the extrusion step was performed using a piston extruder (Fig. 1) designed for industrial applications, as witnessed by geometric characteristics similar to the extruders used in industry.

B. *The extruder*

The material to be extruded is installed in a cylinder with a 175-mm inside diameter and approx. 700-mm long. A die is fit in front of the cylinder. This removable connection allows varying the die geometry independently of its incoming geometry.

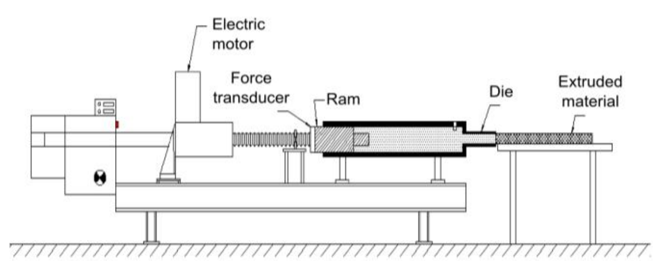

Figure 1. Schematic representation of the extruder

An electromechanical actuator with a 100000-N maximum thrust pushes a piston which slides inside the cylinder and extrudes the product through the die. During the test, a speed is assigned to the piston via an electronic drive unit, which serves to regulate piston speed over an interval extending from 30 to 300 mm/min. A 100000-N force transducer placed between the actuator and the piston indicates the thrust of the assembly. Blocks are extruded in the shape of a standardized rectangular parallelepiped (see Standard EN NF 771-1/CN) without a honeycomb pattern and measuring 105 mm * 60 mm * 220 mm. This type of block is commonly used in France's northern region. Standard EN NF 771-3/CN relative to cement material blocks and Standard EN NF 771-1/CN relative to clayey material blocks list similar dimensional tolerances (height [+3 mm ; -5 mm] and width tolerances [+3 mm ; -5 mm]), which are selected to quantify the blocks' dimensional quality.

III. Materials

A. *Conventional materials*

The sand used in this study was imported from BIALLAIS quarries located in northern France; it is a mixture of Seine River sand and lime with a 0/4 particle size distribution. Its absorption coefficient equals 0.49% while its mass density is 2.61 g/cm^3. The cement (C) used in this study is a CEM I 52.5 N CE CP2 NF supplied by the HOLCIM company.

B. *Wood aggregates*

The two wood aggregate types introduced in this study are of quite different morphologies and origins. The sawdust (S) was obtained from sawing lumber at a mill operated by the ASBOIS company (Pas-de-Calais) and then stored in the laboratory. Wood fibers (F) are produced from wood scraps resulting from sawed lumber (Fig. 2) first crushed in the sawmill to yield coarse particles (with lengths varying from 2 to 6 cm). These scraps were delivered in bulk to the laboratory, where they underwent a second transformation by crushing the coarse fibers using a Fritsch PULVERISETTE 15 type knife crusher with a 2-mm sieve built with trapezoidal openings. The particle size distribution of wood byproducts was determined according to Standard XP P 18-545. The mass densities calculated by applying Standard NF EN 1097-6 equal: 0.390 g/cm^3 for sawdust, and 0.335 g/cm^3 for fibers. The slight difference between these two values is due to the fineness of the sawdust, which reduces the presence of air during measurements. The particle size analysis of both types of wood (aggregate) byproducts is given in Fig.3.

Plant-based materials are known for their high sensitivity to water. As a matter of fact, they absorb a quantity of water that often exceeds twice their weight. This water sensitivity has a deleterious impact on the properties of composites containing such fibers in both their fresh and hardened states [6]. It has proven necessary to quantify this absorption capacity. The physical magnitude has been determined on both types of wood aggregate used herein.

Figure 2. Wood aggregates views

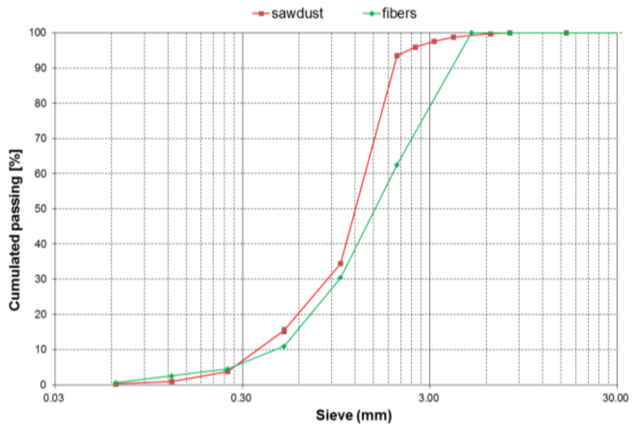

Figure 3. Granulometric curves of wood aggregates

These aggregates were immersed in water for different lengths of time: 1 min, 2 min, 5 min, 10 min, 30 min, then 24 and 48 hours. The absorption rate Ab(t) is derived on the basis of the sample mass at time "t" and expressed as the ratio of the sample mass increase "M(t)" at time "t" to the initial dry mass "Ms".

$$Ab(t) = \frac{M(t)}{Ms} \quad (1)$$

Results obtained reveal that poplar sawdust absorbs more water than crushed fibers (650% for sawdust vs. 585% for fibers), by virtue of the greater quantity of fine particles in sawdust. Inded the quantity of fines increases the specific surface area in contact with water, which leads to a higher level of adsorption. Absorption kinetics yield information on the time required for the microfibers to become saturated. This time amounts to roughly 2 minutes. The water absorption of these aggregates is greater than the values reported for other raw plant fibers (bagasse, coco fiber), which vary between 34% and 400% [7].

IV. The mix designs under study

Replacing sand by wood byproducts has been undertaken using different substitution rates for both sawdust and crushed fibers (see Table 1), in developing a wood mortar mix design that satisfies the extrudability criteria established by Kuder [5]. The mixing process (Fig. 4) has been modified to facilitate the introduction of wood byproducts into the mixes. Before adding cement and sand into the mixer, the wood aggregates are saturated in order to avoid absorbing the amount of water necessary to form the matrix. The substitution of sawdust for sand was carried out for a mortar with a 40% paste volume (MT). Maturity measurement testing conducted on sawdust mortars confirmed that the presence of sawdust in the mortar greatly inhibited setting beyond a 30% substitution rate [8]. For this reason, extruded mixes are developed with substitution rates varying between 10% and 30%.

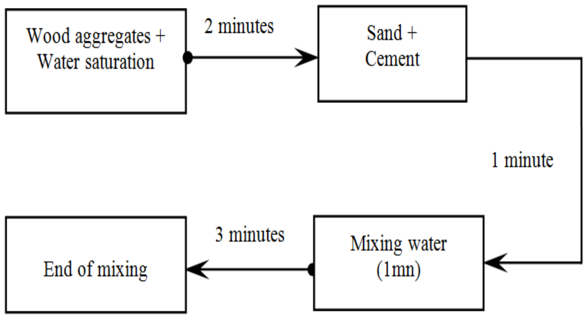

Figure 4. The mixing process

TABLE I. VARIOUS CONCENTRATIONS OF WOOD MORTARS [Kg/m^3]

	Cement	Sand	Water	Sawdust	Fibers	Slump (mm)
MT0	488	1568	244	------	------	30.5
MS10	488	1416	244	23	------	47
MS20	488	1263	244	46	------	100
MS30	488	1111	244	68	------	150
MF10	488	1416	244	------	20	28
MF20	488	1263	244	------	39	90
MF50	488	806	244	------	98	130

The various concentrations are listed in Table 1. For crushed fibers, substitution rates range from 10% to 50%, until an extrudable mix can be obtained.

V. Results and discussion

A. *Rheology of mixes*

Abrams cone tests (see Table 1) show that introducing wood byproducts increases the fluidity of mixes. Several hypotheses can be forwarded regarding the influence of wood particles on the fluidity of a cement material. Tranc Le [6] attributes the rise in fluidity to electrostatic interactions between plant particles and the cement, which would enhance the deflocculation of cement grains. The water bonded to aggregate surfaces might also explain this fluidity increase. During cement matrix - plant fiber interactions, a thick water film is in fact present at the aggregate surface [9], with this film potentially reducing the capacity to capture solid particles. The rheological characteristics of a material are also correlated with the density of its components. Substituting low-density aggregates for sand leads to a drop in mix viscosity. Another very likely hypothesis is the presence of more free water in mortars containing wood aggregates; this heightened presence is due to inhibition of the water-cement reaction subsequent to the chemical reaction between (water-) extractable substances contained in the wood aggregates and cement particles. This level of inhibition lowers the water consumption required for cement hydration, which in turn increases the fluidity of mixes due to the presence of a greater quantity of free water (Fig. 5). The results derived here refute those found by Naik *et al.* [10], who observed a rise in the viscosity of mortars containing plant-based aggregates.

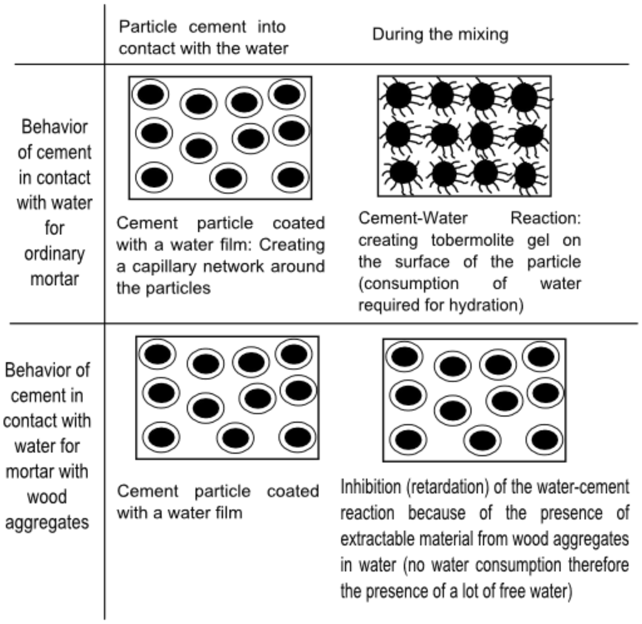

Figure 5.Schematization of interactions mixing water / cement particle during the first minutes of mixing

This contradiction is justified by the saturation of aggregates prior to their introduction into the mix, during a step that avoids reaching the water absorption level necessary for matrix formation.

B. *Mix extrusion*

The extrusion force is closely correlated with the extrudability of the target mix. A study of this mix will allow assessing the influence of substitution rate on mix behavior during the extrusion process. This extrusion force depends on tribological parameters (friction between extruder walls and the material) as well as on rheological parameters (shear at the material/material interface). The extrusion force is the sum of three forces: extruder wall / material friction, material shear at the level of the dead zone, and die wall / material friction, as defined in Fig 6. The force used to determine mix extrudability however is the one needed to achieve a plastic shape (KM); it has been described by several authors [11, 12] and depends to a large extent on phenomena intrinsic to the material (friction between the various aggregates, water migration into the material).

Fig. 7 provides the various maximum extrusion forces reached when extruding both fiber and sawdust mortars. The influence of each wood aggregate shape differs; it is thus suggested to comment on this figure by distinguishing the type of aggregate.

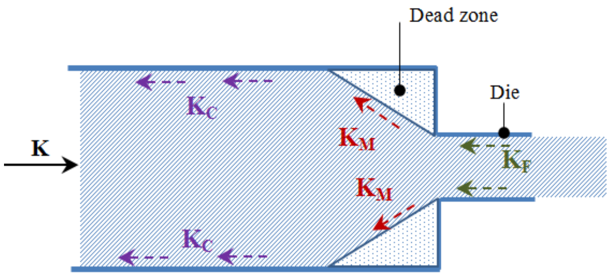

Figure 6. Terminology of the various forces intervener during extrusion, with K = total extrusion force, K_C = frictional force between the chamber walls and the material; K_M = necessary force to reduce the section; K_F = frictional force between the walls of the die and the material.

Extrusion of sawdust mortars:

During incorporation of sawdust aggregates into the mortars, a decline in extrusion force is observed at a low sawdust-for-sand substitution rate. For a 10% substitution rate, the decrease in friction force amounts to approx. 40%. This weaker force is in agreement with the effect recorded on the rheological behavior of mortars containing sawdust. The presence of much greater quantities of free water combined with the deflocculation of cement particles generates enough paste to reduce wall/material friction (K_C and K_F) by means of creating a paste layer at the site of this interface. This weaker force may be attributed to less friction inside mixes containing sawdust as well as to the greater mix fluidity. The sawdust actually allows reducing the sand aggregate surface area entering into contact. The decrease in sand/sawdust friction exposes the material to shear with a weaker force (K_M) and allows for flow through the die.

Extrusion of fiber mortars:

Fiber mortars do not exhibit behavior identical to that of sawdust mortars. At substitution rates of 10% and 20%, extrusion appears to be blocked (maximum force reached equal to 100 kN). The increase in force required to reduce the cross-section (material shear and shaping) at the level of the die entrance is due to the greater intergranular friction (sand-sand, sand-wood) induced by rapid filtration of the liquid phase.

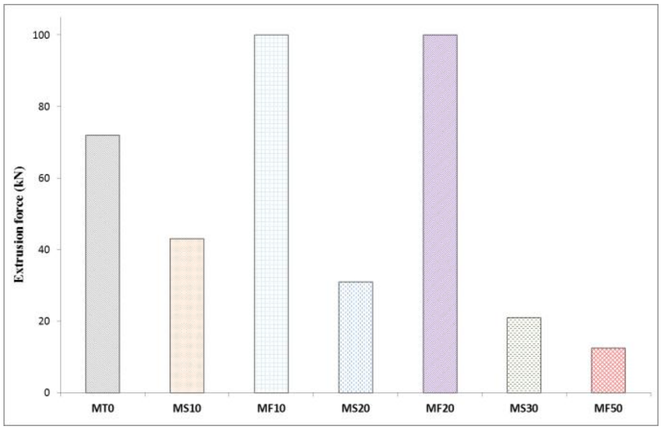

Figure 7. Maximum extrusion forces obtained during extrusion

This filtration causes local variations in the paste-to-aggregate volume ratio. The tremendous porosity generated by the fiber particle size distribution is the reason behind this filtration. The same behavior had been observed by Lombois-Burger [13] when extruding polymer fiber mortars. For fibers, the critical substitution rate to prepare the mix for potential extrusion lies around 50%. At a 50% substitution rate, the concentration of fibers actually modifies rheology of the mix, which becomes more fluid and thus capable of being sheared and shaped with application of a weaker force.

C. *Quality of the extruded blocks*

In order to compare the quality of extruded blocks, shape coefficients "αi" were determined (Equation 2) on three parts of the extruded blocks (Figure. 8).

$$\alpha_i = \frac{D_{re}}{D_{th}} - 1 \qquad (2)$$

with D_{re} denoting the actual measurement and D_{th} the theoretical one.

These coefficients are then compared with allowable tolerances, in accordance with the standards cited above (α_1 and α_2 [+3%; -5%]; α_3 [+5%; -8%]).

An analysis of shape coefficients from these extruded products (Table 2) indicates that the extra slump directly alters the quality of extruded products.

Table II. Shape coefficients of various extruded blocks

	MT0	MS10	MS20	MS30	MF50
α_1	0.3%	1.9%	2.0%	2.9%	9.4%
α_2	5.95%	7.9 %	13.0%	13.3%	26.1%
α_3	-1.67%	-3.8%	-15.0%	-15.2%	-24%

The modification of mix rheology by means of adding sawdust and wood fibers impairs the quality of extruded products. Porosity inside the product rises and related surface defects can be observed on some products (MS30, MF50) (see Fig. 9).

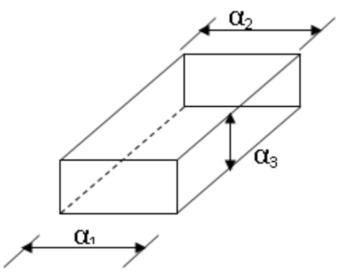

Figure 8. Localization of the different shape coefficients

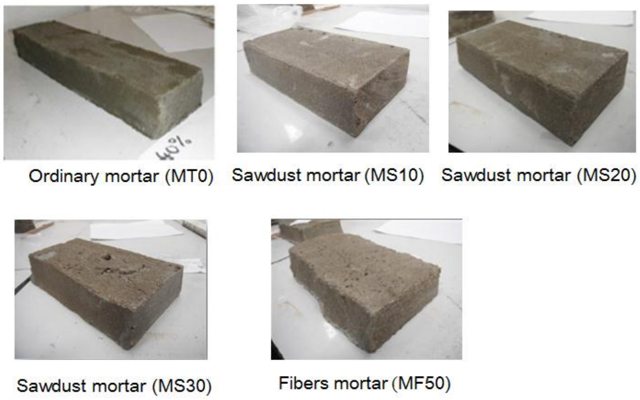

Figure 9. View of the various extruded blocks

VI. Conclusion

This study has served to expose the influence of wood byproducts on the rheology and extrudability of sand mortars. It has been observed that:

- Incorporating wood aggregates modifies the rheology of mixes by making them more fluid.
- Substituting sawdust for sand at a rate of between 10% and 30% has the effect of reducing extrusion forces by 40% to 70%.
- Replacing sand by fibers at rates less than 50% eliminates mortar extrudability despite the additional fluidity. This inability to extrude is caused by the entanglement of fibers, which creates a zone with a very high rate of shear.
- Incorporating 10% sawdust per sand volume only slightly downgrades the quality of extruded products; beyond this 10% threshold, quality is considerably diminished.

Acknowledgments

The authors would like to thank the Nord-Pas de Calais Regional Council for financing this study. We are also grateful to the ASBOIS company, BIALLAIS quarries and HOLCIM cement works in Lumbres for all their support throughout this research project.

References

[1] Jacques Bresson et al (2006). Faisabilité de l'extrusion pour la production des produits minces en micro-béton. Publication du CERIB .

[2] Yixin Shao, Shashidhara Marikunte, and Surendra P.Shah (1995). Extruder fiber-reinforced composites. Concrete international, pages 40–52.

[3] Zahia Toutou, N. Roussel (2005); The squeezing test a tool to identify firm cement based material's rheological behaviour and evaluate their extrusion ability. Cement and concrete research, vol.35, pages 1891–1899.

[4] Fàbio A. Cardoso, Vanderley M. Jhon, Rafael G. P. (2009); Rhéological behavior of mortars under different squeezing rates. Cement and concrete research, vol.39, pages 748–753.

[5] K.G. Kuder et al (2006) ; Capillary rheology of extruded cement-based matérials. M.S. Kontsa Gdoutos (ed) Measuring Minitoring and M Concret Propertie sodeling, pages 479–484.

[6] Tranc Le Ngoc Huyen, M. Queneudec T'Kint, Caroline Remond et al ; Saccharification of Miscanthus x giganteus, incorporation of lignocellulosic by-product in cementitious matrix. Comptes Rendus Biologies,334 (2011) 837.e1–837.e11.

[7] F. Pacheco-Torgal, S. Jalali: Cementitious building materials reinforced with vegetable fibres, a review Construction Building Materirals., In Press, Corrected Proof. doi:10.1016/j.conbuildmat.2010.07.024.

[8] Z. XING – « Bibliographie du projet et l'effet du peuplier sur le mortier », Projet ARCIR Cluster-Bois - Post-Doctorat de l'universite d'Artois, 2012

[9] J.H. Savastano, P.G. Warden, R.S.P. Coutts: Mechanically pulped sisal as reinforcement in cementitious matrices, Cement and Concrete Composites. 25 (2003)311–319.

[10] T.R. Naik, T.S. Friberg, Y.M. Chun, Use of pulp and paper mill residual solids in production of cellucrete, Cement and concrete research. 34 (2004)1229–1234.

[11] Basterfield RA, Lawrence CJ, Adams MJ (2005). Chemical Engineering Science 60 (10):2599-2607

[12] Benbow JJ, Bridgwater J (1993) Paste Flow and Extrusion. Oxford

[13] H. Lombois-Burger, P. Colombet, J.L. Halary, H. Van Damme: Kneading and extrusion of dense polymer–cement pastes, Cement and concrete research. 36 (2006)2086–2097

About Author (s):

J.G. Ndong Engone is a Ph.D. student at the University of Artois affiliated with LGCgE (Laboratory of Civil Engineering and Geo-environment, EA 4515) in northern France (Béthune). He received his research training at the LGCIE Laboratory in Lyon. Mr. Ndong Engone is currently developing a new environmentally-friendly material made from timber industry waste, whereby this material is being shaped using an extrusion technique. His focus extends to the mechanical and thermal characteristics of the blocks obtained after extrusion.

Zhi Xing is Postdoctoral Researcher in the Laboratory of Civil Engineering and Geo-environment (LGCgE, EA 4515) at the University of Artois in France. He received his MS from University of Pierre and Marie Curie and PhD from University of Cergy-Pontoise. His main area of research is ecomaterials and cementitious materials under severe conditions.