Journal of New Technology and Materials(JNTM)
J. New Technol. Mater.
Vol. 07, N°02 (2017)76-83

OEB Univ. Publish. Co.

Modeling of machining chips of steel parts for their recycling and reinforcement of cementitious matrix

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Received date: Feb. 18, 2017; revised date: Nov. 11, 2017; accepted date: Dec 16, 2017

Abstract
This work joins in the context of the recovery of waste production "chips" of steel parts that are found in the industry, cementitious matrix is a means for recycling this type of materials, and indeed these chips play the role of corrugated metal fibers. The presence of these chips in a cement matrix they used, to give the resulting composite ductile behavior and limit the distribution of cracks beneath the effect of sewing and energy absorption. Experimental study was conducted on specimens (40 mm × 40 mm × 160 mm) mortar for both fiber types (standard and chips) to 03 dosages of fiber (5%, 10% and 15%). A numerical simulation of the pull-out chips in the cement matrix has been proposed that take into account the nature, the shape of the fiber, fiber-matrix friction. The results show that the chips can be recycled in the cement matrix as reinforcement.

Keywords: Fibers corrugated (chips); Adhesive; Friction; Modelling; recycled

1. Introduction

The cementitious matrix is a rather brittle material whose compression characteristics are much larger than those of tension [1-4]. To improve these, the matrix was reinforced with steel frames. In order to develop a composite material of ductile behavior in tension experiments to replace these frames by fibers embedded in a more or less random (considered uniform in space) both in the distribution of that 'orientation[5-6]. The work of these fibers is to impart the cement matrix has some structural homogeneity, good tensile strength and good post-rupture behavior. The study of the possibility of recycling of the chips resulting from the machining of steel parts, such as reinforcement for cementitious matrix, in order to assess the contribution in terms of behavior and mechanical properties.

A comparison of performance of the composite thus obtained with those reinforced with conventional fibers will tell us about the eventual possibility of recycling [7-9]. The mechanical characterization of the matrix reinforced by fibers is the study of behavior and the determination of its mechanical properties using mechanical tests (compression and bending).

As part of this work, three dosages chips (5%, 10% and 15%) for both types of fiber (normalized DRAMIX and chip type) are used to strengthen the matrix. The objective of these trials is threefold: the study of the mechanical behavior, the study of the influence of the addition of the chips on the mechanical behavior and the evaluation of the contribution of the chips to improving the mechanical characteristics of composite [10-12].

The modeling of the behavior in pulling of the reinforced concrete of waved fibers is based on the study of the behavior of the fiber in the matrix. A solution to the problem of the modeling of the adhesion waved fiber - matrix was proposed bringing to light the evolution of the Evolution of the visible rubbing coefficient "μ" according to relative displacement of the rough "δ / λ" [13-16].

2. Experimental

2.1. Materials and mix proportions

2.1.1 . Cement

The chemical composition and properties of ordinary Portland cement (CEM I) of Ain El Kebira Algeria used for the manufacture of mortars and concrete are shown in Table 1.

2.1.2. Mortars

The mortars are prepared from cement, water, fiber and standard sand bags packed 1350 ± 5g whose grain size presented in Table 2.

Additionally, wastes of machining chips of steel parts and the standard fiber Dramix (fig 1-a, 1-b).

2.1.3. *Water*

The water used for manufactures mortars and concrete, is a demineralized water to avoid adding further to our formulations contaminants such as heavy metals.

Table1. Chemical and physical characteristics of CEM I

Element	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	$K_2O + Na_2O$	Ignition loss
Content (%)	63.85	23.91	4.17	4.83	1.16	1.48	0.39	1.25
SSB =3370 cm^2/g specific mass = 3260 kg/m^3								

Table2. Grain size distribution of standard sand

Aperture of sieve (mm)	2.00	1.60	1.00	0.50	0.16	0.08
Accumulated (%)	0	7 ± 5	33 ± 5	67 ± 5	87 ± 5	99 ± 1

Figure 1: Standard and Waste of machining chips of steel parts

2.2. Mortars' formulation

The preparation of mortars generally based on the NF EN196-1; [19] the mortars made are mould to prepare test pieces (in triplicates of each material) with dimensions of 40 mm × 40 mm × 160 mm for mechanical tests for 7 and 28 days. The filled moulds were level and stored in a following chamber: temperature 25°C and 90 % humidity. The formulations produced given in Table 3.

Table 3: Mix proportion of mortar mixtures

Designation	Sand (g)	Cement (g)	Water (g)	Fiber (g)	Rapport (%) Fiber /Cement
MT	1350	450	225	0	0
MFR5	1350	450	225	22.5	5
MFR10	1350	450	225	45	10
MFR15	1350	450	225	67.5	15
MFN5	1350	450	225	22.5	5
MFN10	1350	450	225	45	10
MFN15	1350	450	225	67.5	15

FR (Fiber Waste of machining chips of steel parts) and FN (Standard Fiber)

2.3. Mineralogical Analysis

The mineralogical composition of the waste of machining chips of steel parts is determined according to the French standard procedure NF X31-211 [17], by using Scanning electron microscopy coupled with energy dispersive X-ray microanalysis (SEM-EDX) F.E.I. Quanta200 in the laboratory of materials technology of university of Bejaia. Materials analyzed as powders.

2.4. Characterization of fibers in the break resistance

Tries of drive are led on test tubes the form of which is shown on the (fig 2). These test tubes are obtained by inserting a fiber (shaving) into a matrix in resin [7].

The tries are realized on a machine of leading drive "IBERTEST", capacity 200 KN, piloted by computer, at LaMoMS laboratry of mouloud Mammerie University of Tizi Ouzou, Algeria.

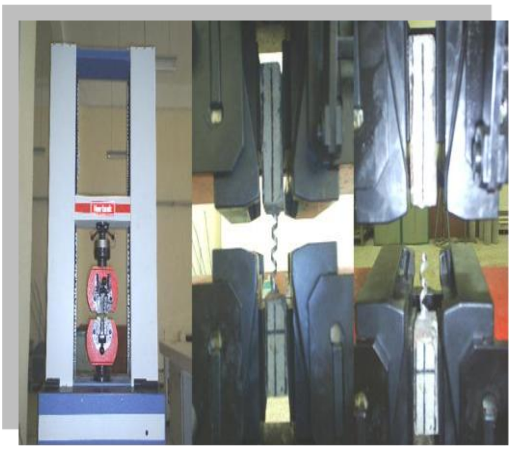

Figure 2: Test of characterization to the rupture of fiber (chips of steel) [7].

2.5. Compressive and flexural strengths

Compressive and flexural strengths were measured out on a press of type 65-L11M2 according to the NF EN 196-1 standard [18-19].

3. Results and discussion

3.1. Mineralogical analysis of the waste (chips of steel)

The XRD patterns of the metallic fibers wastes (fig 3 and 4) shows the mineralogical phases of (SiO_2) associated with some iron and carbon (Fe_3O_4), ($FeCO_3$).

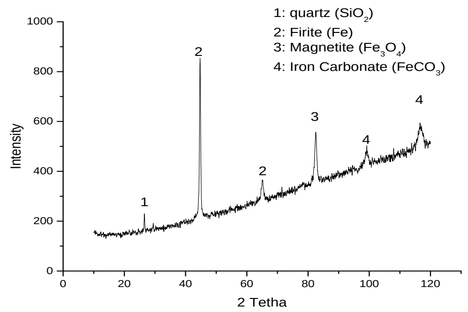

Figure 3: X-ray diffraction of the fiber waste (chips of steel)

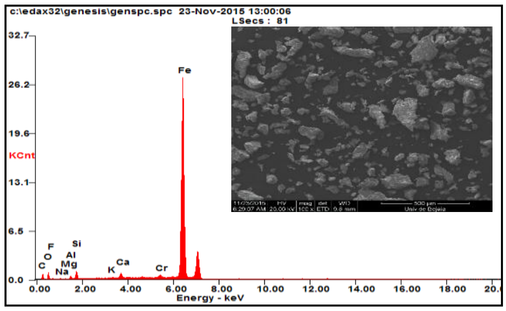

Figure 4: EDAX of the fiber waste (chips of steel)

3.2.Results of characterization to the tensile breakage of waste (chips of steel)

Test results of characterization to the tensile breakage of fibers presented in (fig 5) [7]. During the tests of characterization, we observe a progressive course of the undulations until the total flatness of fiber, follow-up of the lengthening then of the rupture of the latter. The breaking strength average of fibers is equal to 195MPa. We observe a strong dispersion in the results of the three tests. This related to the nature of fibers. Indeed, during the formation of the chips, we have work hardening, plasticization then the shearing of the machined matter. On the surface, according to the mode of cut used, the chips more or less comprise defects, which play the part of starter of cracks.

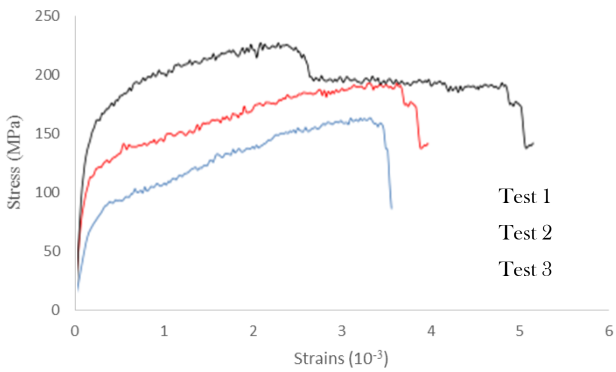

Figure 5: Stress-strain curve of tensile fibres (chips of steel)

3.3 Mechanical strength

Compressive and flexural strengths of materials were followed for 7 and 28 days of cure. (fig 6, 7, 8, 9 and 10) show the evolution of mechanical strengths of mortars made up as a function of times (days). In general, materials at 28 days of curing showed higher strengths than materials at 7 days of curing. This observation is common in studies and experiments dealing with concrete or mortars strength reported in literature [15, 20]. In this study, the results obtained for materials confirm this behavior.

We find that the addition of chips in the matrix commentaries improves the strength and stiffness of the composite, giving it a significant ductility. The behavior of the composite we described by a linear elastic phase before the break, followed by a sudden drop of the effort that has stabilized at a level corresponding to the residual capacity developed in the finals. This behavior is achieved with the flexural tensile tests (fig 6-9). A high content, we have a reduction of compactness, which causes a reduction of the tensile strength and compressive strength. Given the results obtained, the mortar composition, which offers the greatest tensile and compressive strength and the greatest constraint start cracking, is the one containing respectively 5% and 10% fiber.

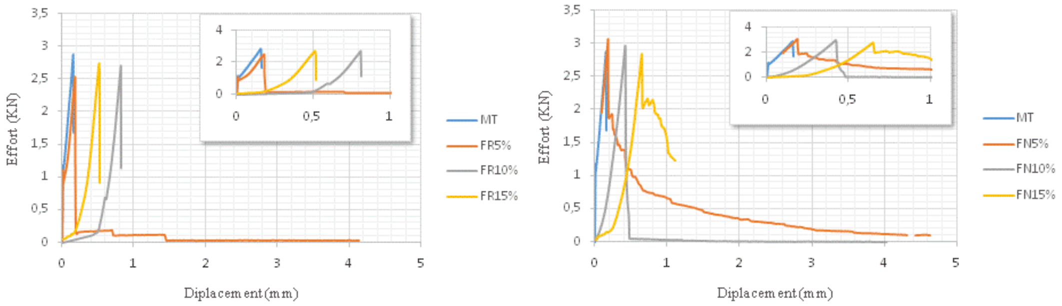

Figure 6: Curve Effort-Displacement in flexural strengths at 07 days of cure

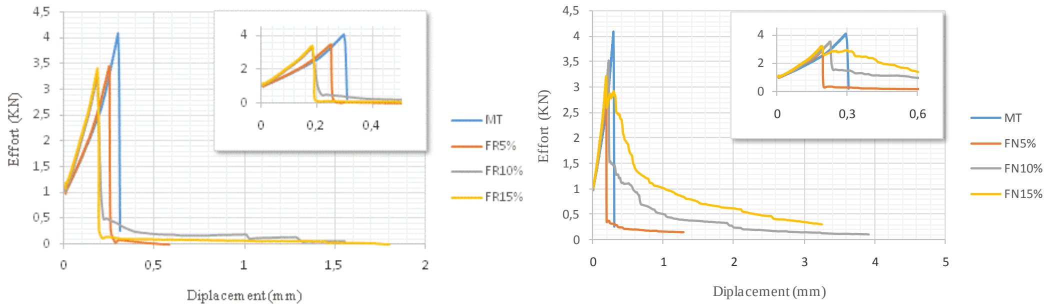

Figure 7: Curve Effort-Displacement in flexural strengths at 28 days of cure

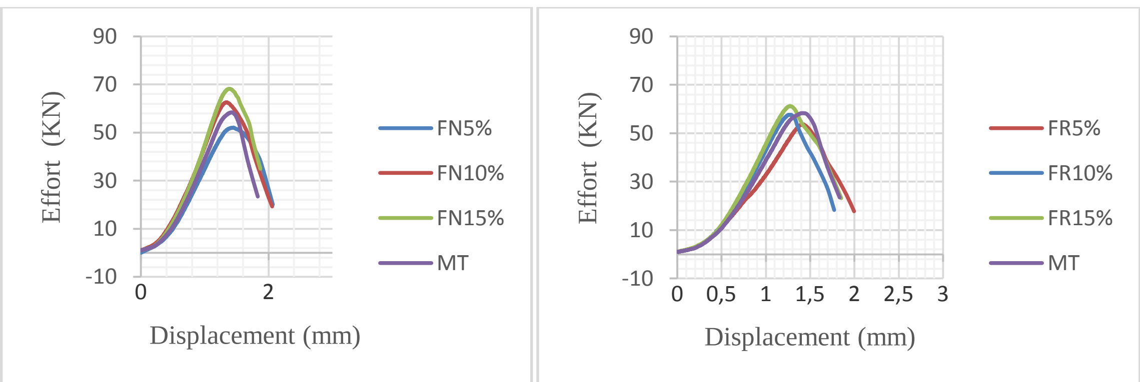

Figure 8: Curve Effort-Displacement in Compressive strengths at 07 days of cure

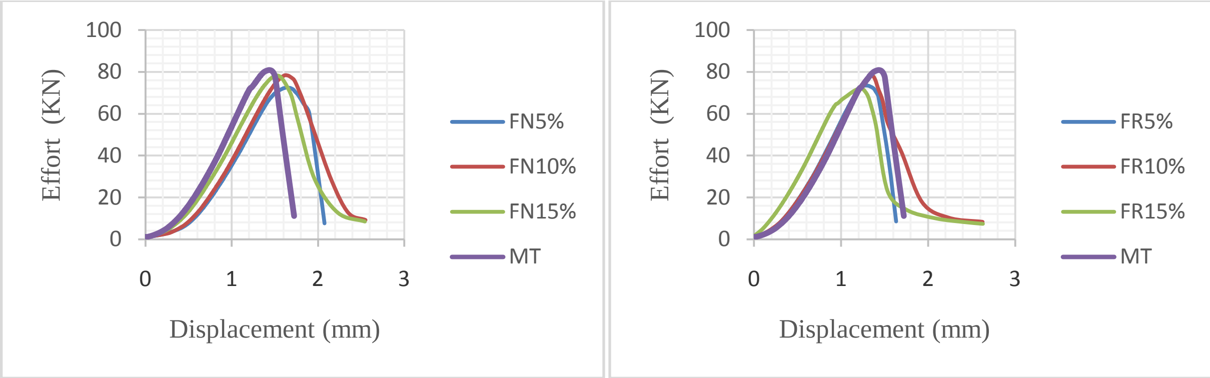

Figure 9: Curve Effort-Displacement in Compressive strengths at 28 days of cure

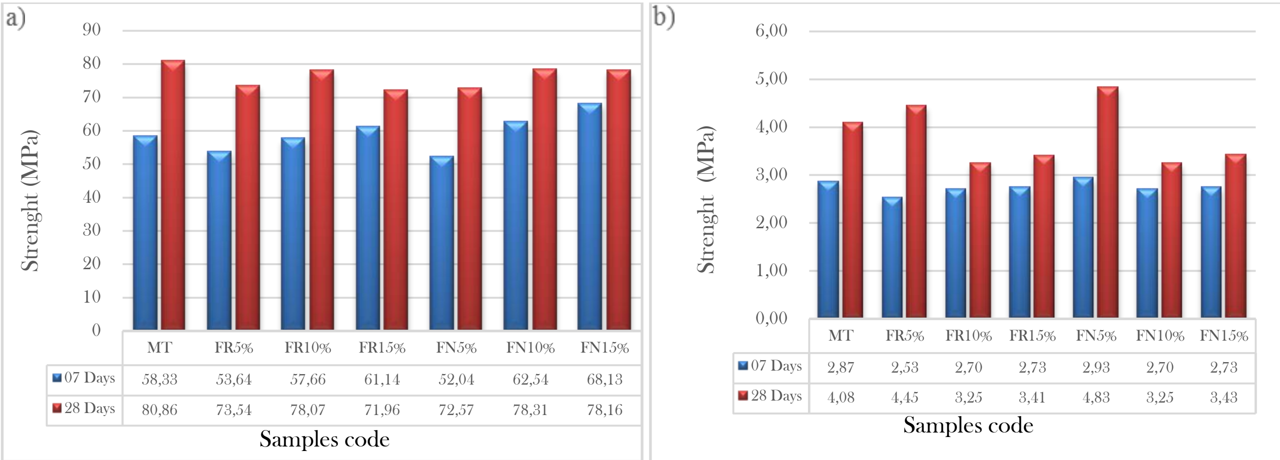

Figure 10: Mechanical strength of mortars (a) compressive and (b) tensile

3.4 Numerical modeling the pulling of the Waste of machining chips of steel parts

The behavior of the composite is elastic linear until cracking of the matrix. The interior studies that one can quote [6], [12] and [14] show that at the instant where appears a crack there are a brutal decrease of the constraint. We interest us in that follows to the behaviour after cracking, therefore after the peak of load. In this domain, one considers the sliding phenomenon of fiber-matrix eventual plasticization of the fiber steel. One expresses then the energizing equilibrium of a fiber at the time of the sliding.

3.4.1. Modeling of the adhesion matrix in mortars Caption

The Waste of machining chips of steel parts (said also to variable geometry) decomposed in curves sections of curvilinear elementary length “ds” (fig 11). The equilibrium can write in the following manner Eqt (1 to 4). The projection of the forces along;

The x axis:

$$P\sin\left(\frac{d\theta}{2}\right)+(P+dP)\sin\left(\frac{d\theta}{2}\right)=dN \qquad (1)$$

The z axis:

$$dP\cos\left(\frac{d\theta}{2}\right)=dT \qquad (2)$$

For the small angle to elementary elements «ds», we can do: $\sin\left(\frac{d\theta}{2}\right)=\frac{d\theta}{2}$ and $\cos\left(\frac{d\theta}{2}\right)=1$

One ignoring the higher order terms $dP\left(\frac{d\theta}{2}\right)$, the equations (1) and (2) become (3 and4) [14]

$$dN = P\,d\theta \qquad (3)$$

$$dP = dT \qquad (4)$$

The equilibrium of an element of Waste (fiber) at the time of the sliding, generated a radial effort dN and the tangential effort of dT. That two efforts can be linked by a friction law of coulomb, this law consists to linking the shear stressτ to the normal stressσ of a facet by a friction coefficient f and a cohesion Co.

We will adopt a coulomb's law in global forces, where the equation (4) as eq (5):

$$dT = \mathrm{f}\; dN + \tau_o\, p\, ds \qquad (5)$$

Where p is the perimeter of the fiber and τ_o is the bond stress between the fiber and the matrix.

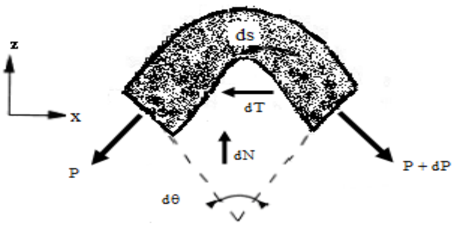

Figure 11: Equilibrium of small element Waste of machining chips of steel parts

Physically at the time of the sliding, a fiber element undergoes, on the one part, a sliding of rigid body of amplitude dδ and on the other part, a variation of curvature (dC) produced by flexion. The chips of steel follows then the print of its initial geometry, the experimental observances [14] showed that each section undergoes a plasticization. The purely statics approach of the chips of steel equilibrium does not permit an assessment of plastic energy dissipated during the sliding of the chips of steel. The equilibrium of this chips element curve must bedescribed from an energy point of view.

The balance of the mechanical energy, applied to the slipping elementary length curve of a chips of steel that, allows to write that the work of the external forces (W_{ext}) is equal to the work of the deformations (W_{def}),

$$W_{ext} = W_{def} \tag{6}$$

The work of the external forces written as Eq (7):

$$W_{ext} = \int_S p_i \, u_i \, dS \tag{7}$$

Correspond to the integration, of the product of the elementary forces "pi .dS", over the external surface of the chips of steel element's, (pi is the pressure exerted on the exterior surface,"u_i" are the kinematic displacement field of the element and "i" is the indication by representing a coordinate in the space.

The strengths of mass, such as the gravity, are disregarded [14].In the field of the displacements considered, only the components of the efforts (P, P+dP and dT) hard working follow the curvilinear axis is taking in account (fig 11). Disregarding the terms of higher order, the equation (7) written as eq (8):

$$W_{ext} = -P\,d\delta + (P+dP)d\delta - dT\,d\delta$$
$$W_{ext} = dP\,d\delta - dT\,d\delta \tag{8}$$

The work of the internal efforts is obtained by integration, over the element's volume V, of the product of the stress tensor σ_{ij} and strain tensor ε_{ij} defined in all dawned of the element's volume eqt (9).

$$W_{def} = \int_V \sigma_{ij}\, \varepsilon_{ij}\, dV = \int_V \sigma\, z\, dC\, dV = dC \int_V \sigma\, z\, dV$$
$$W_{def} = dC\, ds \int_S z\, \sigma\, dS = dC\, ds\, M \tag{9}$$

With: M: bending moment in the fiber, ds: elementary curvilinear length of the chips of steel.

dS: straight section of the element's chips of steel.

Considering the relations (8) and (9), the balance of the mechanical energy can be written Eq (10)

$$dP\,d\delta - dT\,d\delta = M\,dC\,ds \tag{10}$$

Combining the equations (3), (5) and (10), we obtain the equation (11).

$$dP = (P\,f\,C + \tau_o p + M\,C')\,ds \tag{11}$$

Where C' is the first derivative of the curvature C against the curvilinear abscissa. The result of the integration of the Eqt (11) along the chips of steel gives a differential equation of the first order in "P". In order to define the behavior's problem of the wire-drawn fiber in the matrix, the modeling of the chips of steel adhesion stamps (coefficient of rubbing) "μ" is then defined starting from the isostatic equilibrium equations between the asperities in interaction (figure 12) [13]. Roughness rubbing has a sinusoidal profile, it results the following expressions.

$$\mu = (f + \chi)/(1 - f\chi) \tag{12}$$

$$\chi = \pi \frac{A}{\lambda} \cos\left[\pi \frac{\delta}{\lambda}\right] \tag{13}$$

With; **δ<λ/2**, **λ/2**: period, **χ** : the slope of the contact, **A** : amplitude of the rough,

δ : Relative displacement of the rough and **A/λ**≤ 0,015 [13].

In the equation (13), the condition $\delta<\lambda/2$ drive at $[\pi\delta/\lambda] < \pi/2 \Rightarrow \chi = 0$ from where; $[\delta/\lambda] < 1/2$.

The equations (12) and (13) make it possible to plot the curve representing the evolution of μ according to the ratio [δ/λ] (figure 3). This one makes it possible to fix the coefficient of apparent friction. Consequently, the variation of the tangential stress T given by the equation (6) is transformed into equation (14).

$$dT = \mu\, dN + \tau_o\, p\, ds \tag{14}$$

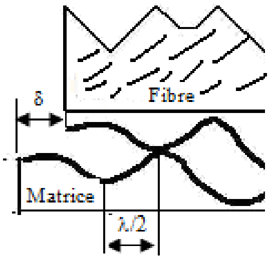

Figure 12: Sinusoidal profile of the roughness rubbing

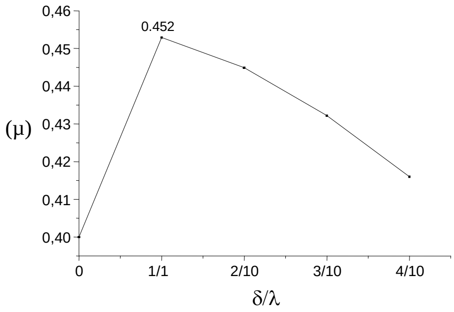

Figure 13:Evolution of the visible rubbing coefficient μ according to δ /λ

Finally, the expression of the effort " $P(s)$ " necessary to pull the wire-drawn fiber of the matrix, is given by the combination of the Eq. (10, 14), the Eq. (15) obtains some after integration over the length of the fiber [6].

$$P(s) = \frac{\tau_o p + MC'}{-\mu C}\left(e^{\mu C s} - 1\right) \quad (15)$$

The developed model makes it possible to describe the behavior of a fiber undulated during its wrenching of a matrix. It makes it possible to plot the curve effort of wrenching according to displacement. The confrontation of the curves obtained by the model suggested and the curves obtained on tests of wrenching for lengths chips of steel parts (ℓ_f = 16 mm), for **FR**10% and **FN**10% is given to the (fig.14)

The result of this confrontation is rather satisfactory. The shape of the experimental curves is correctly approximate.

The model suggested is based on the application of the theorem of mechanical conservation of energy. The behavior is described using a first order differential equation. It made friction with the interface matrix fiber, the radial stress modifying those of shearing and the plasticization of steel. These phenomena are brought into play during the wrenching of chips of steel.

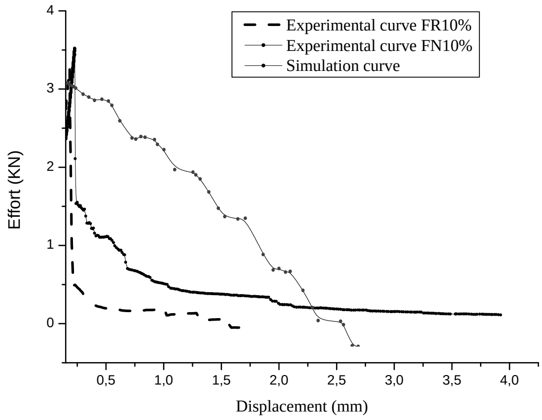

Figure 14:Comparison of resultsforce – displacement (ℓ_f = 16 mm)

4. Conclusion

Characterization by direct tensile testing of the mechanical behavior of the fiber-reinforced matrix has demonstrated that the presence of the chips results in increased resistance to cracking of the composite and a ductility intake behavior in its position - Out.

This behavior is described by a linear elastic phase before the break, followed by a sudden drop of the effort to stabilize at a level corresponding to the residual bearing capacity, developed in the finals.

Compressive tests show that the addition of low percentage fibers brings a slight increase in strength and stiffness, for cons, with the increased volume of the fibers; the mechanical properties rather tend to decrease.

Flexural tensile tests reveal a significant improvement in behavior brought by the chips. This improvement appears clearly in the post-cracking field which has an important bearing ductility.

Comparison of mechanical properties of mortar reinforced with chips with those of mortar reinforced with standard fibers **DRAMIX** shows that the chips give the mortar witness a substantial increase in resistance.

With a significant increase in resistance and a significant contribution of ductility in the post-fracture behavior of the composite, the recycling of chips as reinforcement for the cement matrix becomes interesting.

A parametric study made it possible to model the friction of fiber undulated in matrix and to highlight the evolution of the evolution of μ according to the ratio [δ/λ].The software, making it possible to follow the nonlinear behavior until the rupture of a concrete section, proposed by [15], is used to validate this modeling. The results of confrontations carried out are satisfactory.

Acknowledgements

We thank the Ministry of Higher Education and Scientific Research for grants for this research study as well as those of the CNEPRU No: J 0400520060036. The authors appreciate the collaboration of laboratory technicians to process engineering from the University of Bejaia and laMoMS the University of Tizi Ouzou.

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