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Effects of sediment on mechanical behavior of polypropylene fiber concrete before and after exposure to high temperature

Effets des sédiments sur le comportement mécanique du béton de fibre de polypropylène avant et après exposition à température élevée

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Bilel Boulakoud
ORCID: https://orcid.org/0000-0003-3756-7214
Civil Engineering Department, Faculty of Construction Engineering, University Mouloud Mammeri of Tizi Ouzou, 15000, Algeria
LMPC Laboratory, University Abdelhamid Ibn Badis of Mostaganem,27000, Algeria
E-mail: bboulakoud@gmail.com

Abstract

The phenomenon of siltation of dams causes in Algeria a vital problem which annually loses a considerable volume of water storage.The objective of this study the valorization of calcined sediment from the Fergoug dam (western Algeria) in normal concrete exposed at 800 °C. Moreover, the sediments were calcination-treated at 750°C for 5 hours tomakeitactive. The different mixtures were prepared with 0%, 8%, 12% and 16% of sediment by partial substitution of cement , as well as of polypropylene fiber volume of 0.05% and 0.1%. All mixes were investigated on compressive strength and flexural strength at 90 days with different heating cooling cycles from the room temperature to 800 °C in electric muffle furnace. The experimental result indicates that the inclusion 8 and 12% of calcined sediment with fiber significantly enhances properties of normal concrete before and after heating, respectively.

Keywords: Calcined sediment, Flexural tensile strength, Polypropylene fibre, High temperature, Normal concrete.

Résumé

Le phénomène d'envasement des barrages pose un problème vital en Algérie qui entraîne chaque année la perte d'un volume considérable de stockage d'eau. L'objectif de cette étude est la valorisation des sédiments calcinés du barrage de Fergoug (Ouest Algérien) en béton normal exposé à 800 °C. De plus, les sédiments ont été traités par calcination à 750°C pendant 5 heures pour les rendre actifs. Les différents mélanges ont été préparés avec 0%, 8%, 12% et 16% de sédiments par substitution partielle de ciment, ainsi que des fibres de polypropylène en volume de 0,05% et 0,1%. Tous les mélanges ont été étudiés pour la perte de masse, la résistance à la compression et la résistance à la flexion à 90 jours avec différents cycles de chauffage et de refroidissement de la température ambiante à 800 °C dans un four à moufle électrique. Le résultat expérimental indique que l'inclusion de 8 et 12 % de sédiments calcinés avec des fibres améliore considérablement les propriétés du béton normal avant et après chauffage, respectivement.

Mots clés: Sédiments calcines, Résistance à la flexion, Fibres de polypropylene, Haute température, Béton normal.

1. Introduction

The accumulation of sediments in reservoirs denotes a vital problem which causes a reduction in the storage capacity of dams (Safer *et al.,* 2024). In 2020, the National Agency for Dams and Transfers (ANBT) noted that the siltation of the Fergoug dam reached 94.33% (Belaribi, *et al.*, 2024) . However, the reasonable solution of substitution of the fractions of the cementitious materials by the dredged sediments of the dams has undoubtedly economic, ecological and technological advantages (Belas *et al.,* 2013; Sadok *et al.,* 2024). In addition, Belas *et al., (*2014) found that the calcined sediment as cement substitution improves the pozzolanic activity, compressive strength and durability in mortar and concrete. According to Elahi *et al., (*2010) the pozzolanic activity explained by the coupling effects of calcium to pozzolan can be beneficial, a low calcium /silica ratio, improve hydration reaction to produce additional pozzolanic calcium-silicate-hydrate (C-S-H) gel and enhances the mechanical strength of concrete. In addition, pozzolanic activity is related by alumina contents, active silica, amorphousness, particle size and specific surface area of the pozzolanic addition (Walker *and* Pavía, 2011). Researchers Bouhamou *et al., (*2016) and Laoufi *et al., (*2016) show that the use 10%, 20% and 30% of calcined mud have advantages to improving flexure strength.

On other hand, at room temperature, adding polypropylene fiber in mixtures positively affect the compressive strength (Suiffi *et al.,* 2021). However, the addition of polypropylene fibres led to increased ductility, flexural strengths and flexural toughness (Latifi *et al.,* 2022) . Ibrahim *et al., (*2019) stated that the flexural strengths increase with the increasing of the volume fraction of polypropylene fiber content thus reaches the maximum value at fiber content about 0.36%. The inclusion of polypropylene fiber and pozzolanic material shown a great contribution to eliminate weakness of concrete. This can be explained by the combined effect between polypropylene fiber to provide adequate tensile strength to concrete, which increased the first-crack and pozzolanic material seemed to enhance fiber -matrix in concrete (Alhozaimy *et al.*,1996).

Fire represents one of the most severe environmental catastrophes that affect concrete. After the exposure to elevated temperatures, concrete undergoes significant physico-chemical modification (Haddad *et al.*,2004). According to Benali et al. (2021), at high temperature polypropylene fiber content of 0.5, 1 and 1.5kg/m^3 have no significant effect on residual compressive strength and flexural tensile strength. , whereas the presence fiber increase the permeability and mass loss of normal concretes. However, many studies have shown for minimizing the high temperature damage, various mineral addition are used in the mixtures (Boulakoud *et al.*, 2023; Abdelmelek and Lubloy, 2022). In another study Aoual-Benslafa *et al., (*2017) which revealed that the addition of dredged sediments very positively affects the mechanical and physical properties of concrete. The objective of this work is to test the impact of incorporation of calcined sediment in concrete blended with polypropylene fiber on the physical and mechanical performance of ordinary concrete before and after exposure to temperature.

2. Materials and methods

The cement used is a CPA CEM I 42.5 from the Zahana plant (Mascara, Algeria), that complies with the standard (AFNOR NF EN 196-6, (2018)). Specific surface area by Blaine (SSB) and density of cement were 3219 cm^2/g and 3.13 g/cm^3, respectively. The sediments used in this research were collected in the downstream from the Fergoug dam, Mascara Province, Algeria. the raw sediment is calcined at 750 °C for 5 h (Figure 1) according to Sadok *et al.* (2021).The specific gravity and SSB of calcined sediment (C-S) were 2.66 g/cm^3 and 6900 cm^2/g, respectively. The grain-size analyses of the CEM 1 and calcined sediment (C-S) are shown with a grading curve in Figure 2. The chemical compositions of the CEM 1 and C-S were determined using X-rayfluorescence (XRF) spectrometry, and the results are shown in Table 1.

One type of fibres has been used (Figure 2), the polypropylene fibres fibre (PP-F) provided by the TEKNACHEM company from Algeria. The physical properties of these fibers are: length (12 mm), diameter (0.032mm), density (910Kg/m^3), melting point (160 °C), modulus of elasticity (3.7 GPa) and tensile strength (0.45 MPa).

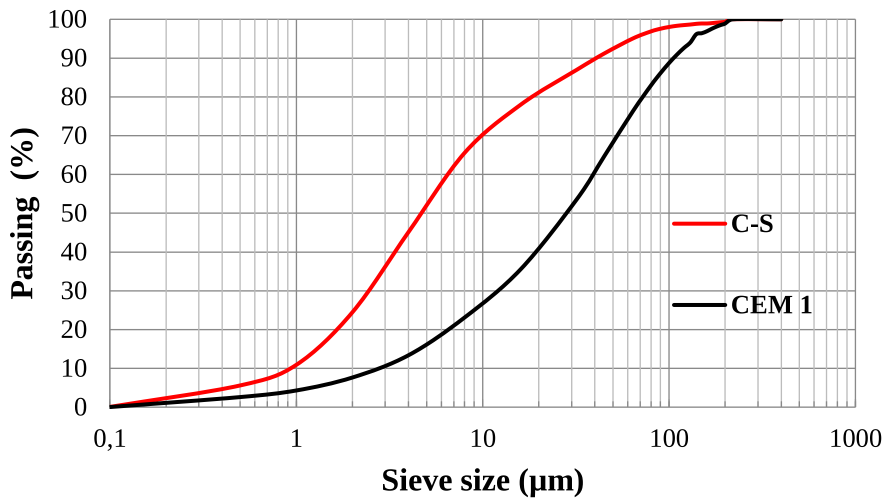

Figure 1- Gradation curve of the CEM 1 and C-S.

Table 1- Chemical composition of the CEM 1 and C-S.

Components (%)	SiO2	Al2O3	Fe2O3	CaO	MgO	SO3	K2O	Na2O	Cl^-
CEM I	20.58	5.55	4.966	61.64	1.453	2.44	0.545	0.24	0.006
CS	60.4	15.44	5.96	3.46	3.05	0.23	2.73	0.58	0.096
	(SiO2+ Al2O3+Fe2O3=81.8) > 70% (ASTM C 618-22 ,(2022))								

(a) (b)

Figure 2 – (a) C-S and (b) PP-F used in the mixture.

The aggregate used is natural siliceous sand (0/3 mm fraction) of specific gravity 2.64 g/cm^3, of fineness modulus 2.75, and coarse aggregate used is crushed calcareous gravel (fractions 3/8mm and 8/16 mm) of specific gravity 2.68g/cm^3 obtained from North-West of Algeria (Sidi Bel Abbes area). The particle size distribution of individual aggregate fractions is shown in Figure 3.

The used additive was a superplasticizer Sika Plastiment BV-40 marketed by the Algerian company Sika El-DJAZAIR in accordance with (NF EN934-2, (2012)). The superplasticizer density was 1.18 g/cm^3, and a dry extract percentage from 36.6 to 40.4 %. It was added to the concrete mixtures to maintain the desired workability. In this study, drinkable water was used for mixing and curing of specimens.

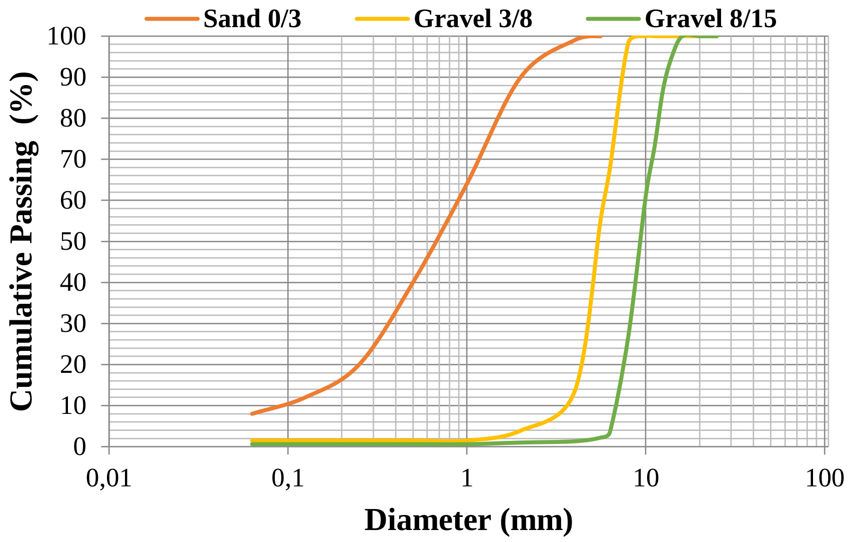

Figure 3 – Particle size distributions of aggregates used in concrete.

In this work, nine mixes have been formulated according to the Dreux-Gorisse method (Dreux and FESTA, 1998). All of the investigated mixes were proportioned with a constant water to binder ratios (W/B) of 0.45 and the gravel sand ratio (G/S) of 1.65. The superplasticizer dosage of concrete optimized to obtain good workability in the fresh state (slump test between 50 and 90mm, consistency class S2). The details of the mix proportions are summarized in Table 2.

Table -2 Details of the mix proportions in kg/m^3.

Notation	CEM I	CS	PP-F	Gravel (3/8)	Gravel (8/15)	Sand (0/3)	Water	BV-40	Slump test (mm)
C0	400	0	0	146	1006	670	180	2	7
C0-0.05	400	0	0.455	146	1006	670	180	2	6.1
C8-0.05	352	32	0.455	146	1006	670	180	2.2	6
C12-0.05	400	48	0.455	146	1006	670	180	2.4	5.9
C16-0.05	368	64	0.455	146	1006	670	180	2.6	5.7
C0-0.1	352	0	0.910	146	1006	670	180	2	5.6
C8-0.1	400	32	0.910	146	1006	670	180	2.2	5.5
C12-0.1	368	48	0.910	146	1006	670	180	2.4	5.4
C16-0.1	352	64	0.910	146	1006	670	180	2.6	5.3

All mixtures manufactured using the same mixing protocol (AFNOR (2002)). Fibres were added at the final stage and dispersed manually. The constituents were mixed for two minutes after the introduction of the fibre. After 24 hours, the moulds were denuded and all concrete specimens have been cured at a normal water temperature (20 °C ± 2 °C) for 7 days and then stored in a dry room at a constant temperature (20°C ± 2 °C) and relative humidity (50 ± 5%) up to an age of the time of testing. At 90 days of age, the specimens from each composition were exposed to elevated temperatures of 800°C with a rate of 2 °C/min in electric muffle furnace (Ezziane 2012).

The concretes specimens were weighed at room temperature and after exposure to a specific elevated temperature. The quantity of mass loss in the samples is expressed as a percentage of the mass. The mass loss is given by the following equation (1):

$$\text{Mass loss} = \frac{M0 - MT}{M0} \times 100\ \% \qquad (1)$$

Where, M0: the mass of the concrete specimens before heating [Kg], and MT: the mass of samples after heating-cooling [Kg].

Before and after heating at the age of 90 days, the compression tests (AFNOR NF EN 12390-3 , (2003)) are carried out on cubic specimens with the dimensions of 100×100×100mm, under the AUTOTEST 2000kN hydraulic press (Figure 4a) . The values is reported the compressive was obtained from equation (2).

$$fc = \frac{F}{A} \qquad (2)$$

which F_{max} refers to the compression failure load [N] and A is the cross section of the test tube[mm²].

After reaching 90 days, for each type of concrete and on heated and unheated specimens, samples are tested in three-point bending (AFNOR NF EN 12390-5,(2009)). Prismatic specimens of 100 ×100 ×400 mm, were tested under the IBERTEST 200kn hydraulic press (Figure 4b). The values is reported the flexural strength was obtained from equation (3).

$$ft = \frac{3FL}{2bh^2} \qquad (3)$$

Where: F is the max flexural load [N], L is span length [300 mm], b and h [b=h=100 mm] are width and height of beams, respectively.

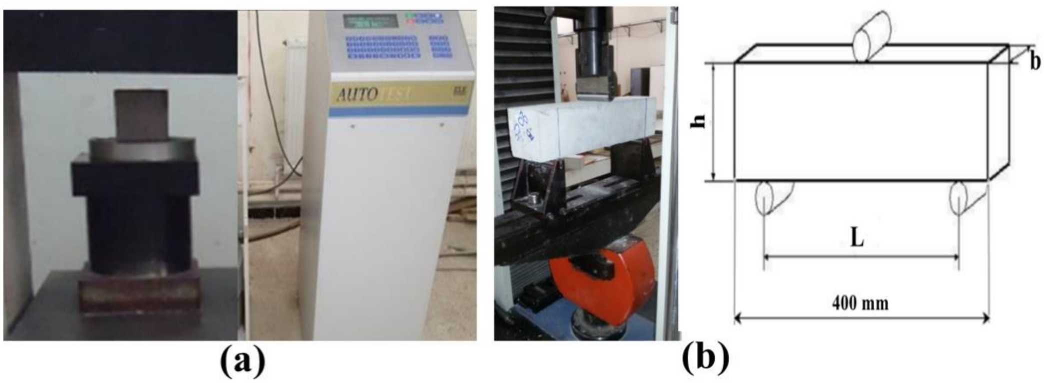

Figure - 4 Apparatus used for the compressive (a) and three-point flexural (b).

3. Results and analyses

3.1. Weight Loss

As demonstrated in Figure 5, the addition of PP-F affect the concrete mass loss .The mass loss for 0.05 and C0-0.1concrete were increased by 4%, and 10%, respectively in comparison with the control concrete C0. These results were in agreement with those relating to the melting and evaporate of fibers at about 170°C.

On other hand, increasing C-S replacement content in all concrete led to reducing the weight loss values. In comparison to the control mix, the weight loss values reduced by 8%, 12%,9%, for 8%,12%,and 16 % C-S mixes, respectively.

The reduction in the weight loss values of pozzolanic specimens at high temperatures was due to pozzolanic activity, which improves the permeability properties, and prevents the release of free water (Izadifard *et al.* 2021).

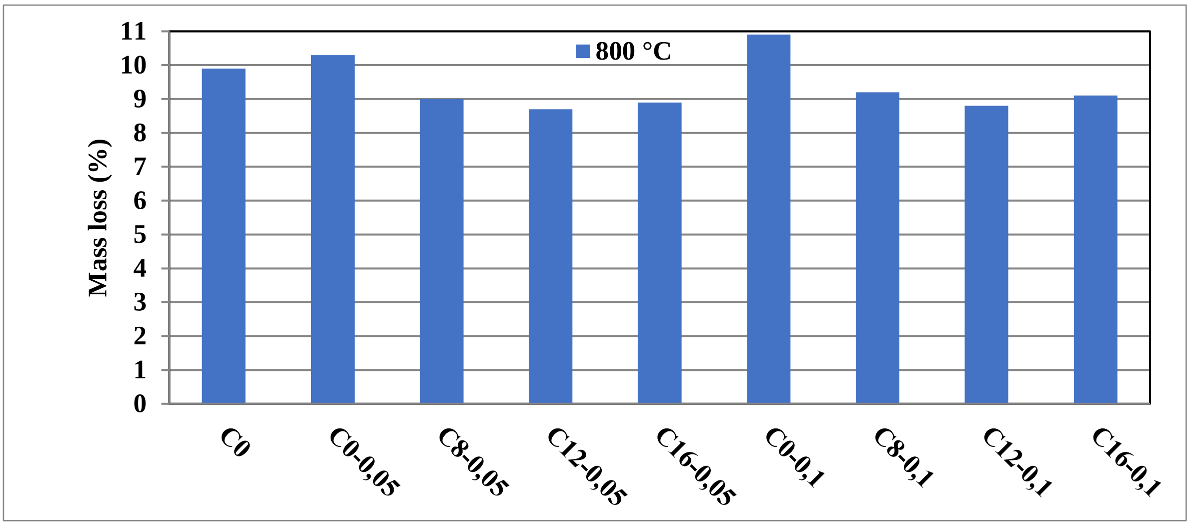

Figure – 5 Mass loss of the various mixtures.

Moreover, as shown in Figure 6. the introduction of 0.455 kg/m^3 and 0.910 kg/m^3 has no significant effect on the spalling phenomenon for the various F-PP concretes during exposures to 800°C. These findings are in agreement with other research work of Amancio *et al.* (2018).

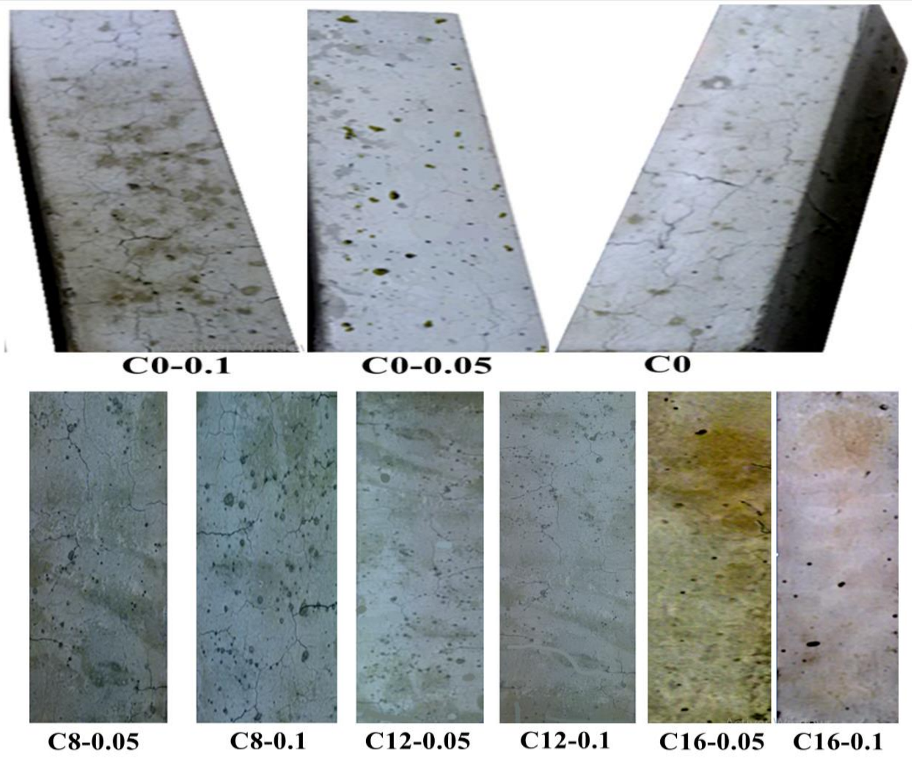

Figure – 6 Specimens exposed to temperature of 800°C.

3.2. Compressive strengths

Figure 7 shows the evolution of the compressive strength of different concrete as a function temperature. It is seen that, at 20 °C the compressive strength of the C0 concretes was 56 MPa. As the PP-F content of the mixes increased, there was a little increase of compressive strength of 5% for C0-0.5 and C0-1 mixes, respectively, as compared to C0 concrete.

The substitution of 8% C-S by weight of cement provides the optimum improvement for the concrete at ambient temperatures. The compressive strength of C8-0.05 and C8-0.1 are 7% (C12-0.05 :4%) and 12% (C12-0.1 :10%) , respectively, higher than plain concrete C0. The improvement in the compressive strength is attributed to pozzolanic activity between cement hydration and pozzolanic materials lead to producing additional C-S-H gel.

On the other side, concrete with 16% of CS and PP-F showed lower compressive strength than the other concrete. The compressive strength of C16-0.05 and C16-0.1 concrete decreased by 8 and 5%, respectively, as compared to C0 concrete. This effect can be explained by the slow pozzolanic activity (Safer *et al.* 2018).

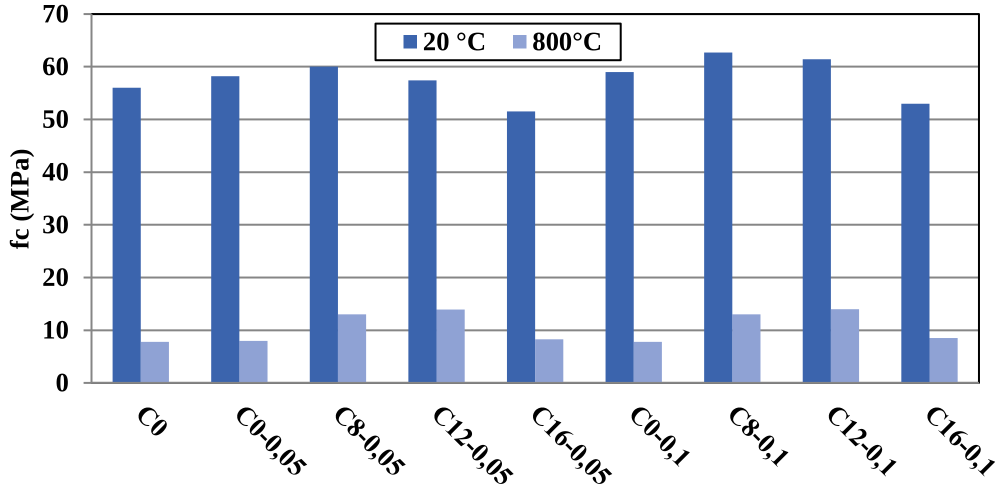

Figure – 7 Compressive strength as temperature.

After exposure to high temperatures, the compressive strength reduced for all concretes. the reduction of compressive strength at 800 °C, due to the physic-chemical transformations of cement paste results in more shrinkage and crystallization of new compounds (Xie *et al.* 2018).

At 800°C, the evolution of the compressive strength of control concrete C0 (7.8 MPa) is similar to that of concrete with PP-F and without C-S. The used of C-S improves the compressive strength. For each specimen with PP-F, increasing the content of C-S with 8% ,12% and 16% increases strength by about 67,79 and 8%, respectively, when compared to C0 specimen at these temperatures. Accodding to Izadifard *et al.* (2021) the high temperature causes hydration. Also, the compressive strength increased in heated pozzolanic specimens due to increasing the number of pozzolanic grains. This grains rise can significantly improve the pozzolanic effect and lead to the product more secondary of C-S-H gel.

3.3. Flexural tensile strengths

As seen in Figure 8, at all temperature, the single peak of load was observed for all concrete. The peak showed the first crack load and indicates the maximum value of load for calculating the flexural tensile strength. The peak load values of flexural strength decreased as increasing the temperature for all concretes was due to the reduced concrete stiffness. Before cracking in all composites, an almost linear elastic region, any crack was not observed, though there is a difference in peak load. The differences in the peak load values are proportional related to addition of C-S. In Figure 9, the room temperature flexural strength of C0 and C0-0.05 was measured 4.6 MPa. The adding of 0.1% PP-F presented a little increase in the flexural strengths for C0-0.1 concretes around 2% as compared C0 concrete at 20 °C.

However, the inclusions of C-S increase in the strength of matrix. The higher values of peak were obtained for fiber mixture with 8% C-S at room temperature. On the other hand, the higher values of peak load were obtained for mixture containing 12% CS and PP-F at high temperature. Moreover, the flexural strengths of C8-0.05 and C8-0.1 concrete is increased by 11% (C12-0.05 :4%) and 13% (C12-0.1 :11%) , respectively, when compared with the C0 concrete . The improvement of pozzolanic specimens can be attributed to pozzolanic reaction. On the other hand, the use 16% C-S with PP-F , flexural strengths decreases by 11% and 4 % for C16-0.05 and C16-0.1 concrete, respectively, as compared C0 concrete at 20 °C.

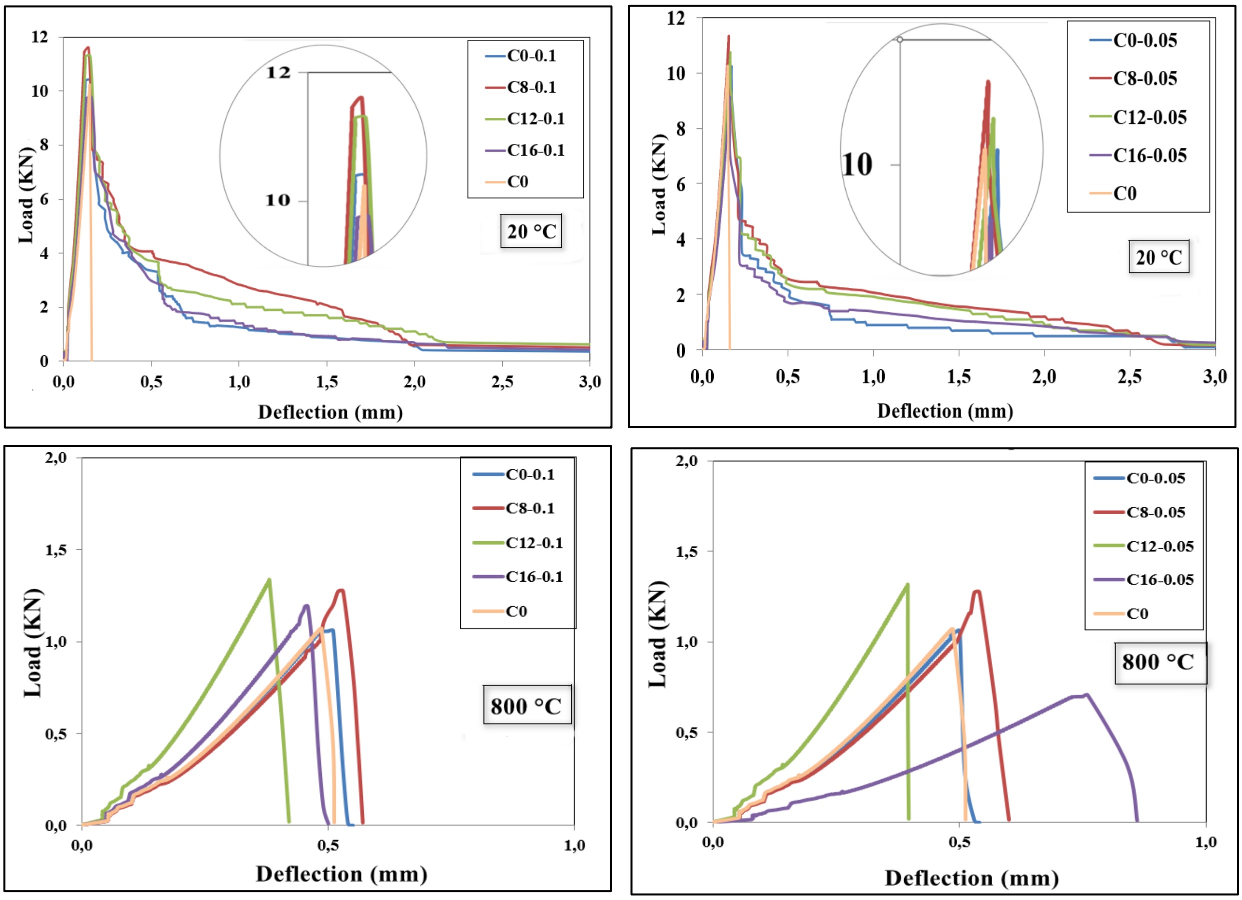

Figure – 8 Load–deflection curves for three-point flexural testing as temperature.

After the linear elastic region, a non-linear behaviour is observed for all PP-F reinforced concrete at 20°C in which the composite remains ductile than the matrix alone .These findings are in agreement with other research work (Dawood *et al.* 2020 ; Yan *et al.* 2021). At 800°C , with the appearance of first crack for all PP-F specimens the considerable loss of flexural strength occurred and all specimens have collapsed directly. The strengh for all concretes showed significant decreases. The flexural strength valus for all concrete was almost 0.6 MPa. The flexural strength is more influenced on the cracking than physico-chemical modifications while the compressive strength related to these two factors (Ezziane *et al.* 2011).

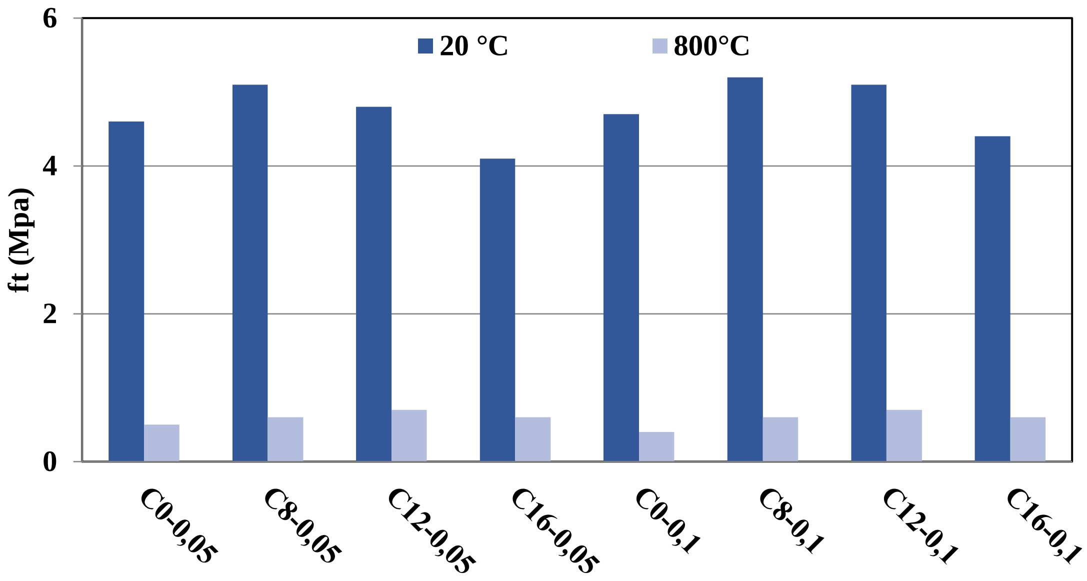

Figure – 9 Flexural strength as temperature.

4. Conclusion

In this experimental study, we evaluated the physical and mechanical properties of normal concrete with calcined sediments content i.e. 0%, 8%, 12% and 16% by cement mass and polypropylene fiber with different percentages of 0.05% and 0.1% before and after exposed to elevated temperatures. From the results, the following conclusions are made:

- As the temperature rises the presence of fiber in the concrete without C-S negatively affects the mass loss. The addition of C-S effects the values, while the 12% of CS and 0.05% PP-F mixture, presented a lower mass loss as compared to other mixture.
- At room temperature, the maximum mechanical properties of PP-F mixtures without C-S were recorded for C0-1 concrete, whereas at 800°C, the presence of PP-F in mixtures has no significant effect on mechanical performance.
- Generally, a combination of PP-F and C-S showed a good mechanical performance as compared to plain mixture. Furthermore, the trends of the compressive strength was similar than that the trend of flexural strength at all temperature. At room temperature, the specimens containing 8% of C-S and 0.1% PP-F had the highest compressive strength and flexural strength, whereas the maximum mechanical properties values were observed on the 12 % of C-S and 0.1% PP-F at high temperature.

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