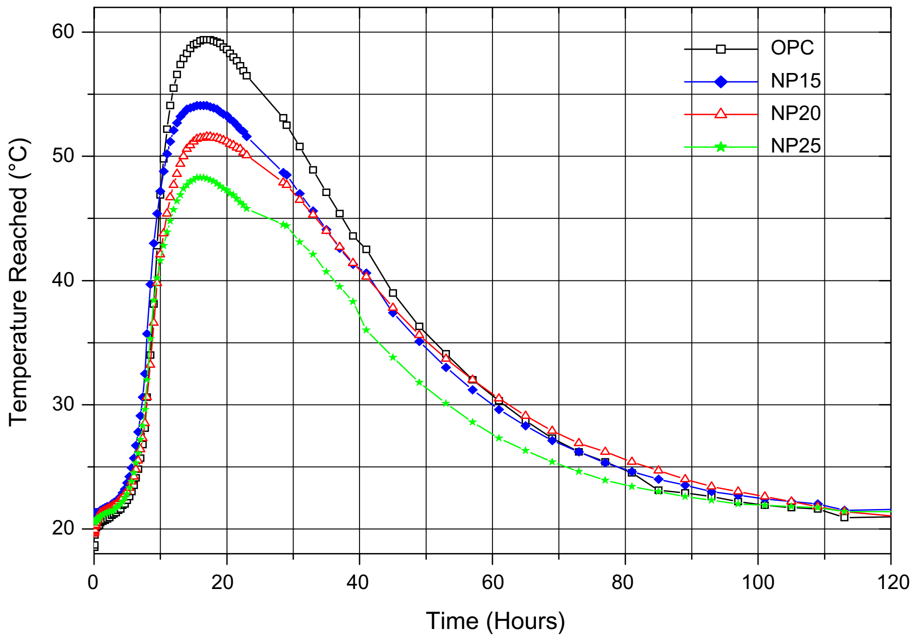

Figure 8. Temperature reached by mortar versus time.

Table 5. Heat evolution of mortar.

Sample	Maximum temperature (°C)	Temperature reduction (%)	Time after casting of highest temperature rise (h)	Maximum heat of hydration ($J\ g^{-1}\ h^{-1}$)	Total heat of hydration after 120 hours ($J\ g^{-1}$)	Reduction of total heat after 120 hours (%)
OPC	59.4	—	17.0	63.6	430.2	0
NP15	54.1	9	17.5	54.9	382.7	11
NP20	51.6	13	18	52.6	357.1	17
NP25	48.3	19	17.0	46.8	271.3	37

ing cement hydration. However, its pozzolanic reactivity could be improved or modified by employing the appropriate activation and (or) treatment (Caijun, 2001). The optimisation of the use of natural pozzolanic material is still under investigation and results are expected to be published later. In addition, due to the continuation of this reaction and the formation of a secondary C-S-H that enhances the paste–aggregate interface and decreases the capillary porosity of the mortar, a greater degree of hydration is achieved, resulting in strengths at 360 days of age which are comparable to those of ordinary portland cement specimens.

Substituting high percentages of pozzolan for cement (more than 20%) leads to considerable compressive strength reduction. This is in agreement with previous research (Durning & Hicks, 1991), which reported that the use of NP beyond 20% replacement resulted in a slight decrease in the compressive strength. This shows that pozzolan has

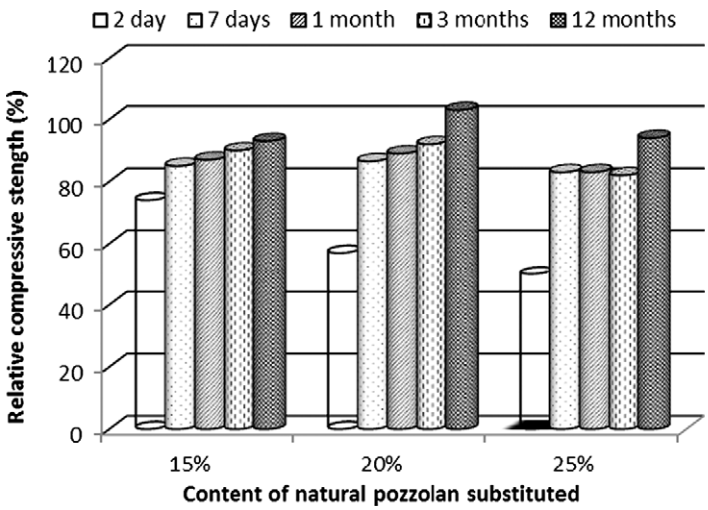

Figure 9. Relative strength for various binders.

a negative effect on the compressive strength when used at high doses. In other words, some of the substituted pozzolan cannot take part in the pozzolanic reaction with cement hydration products and remains inactivated in the mixture, thus reducing its resistance. So, from the point of view of compressive strength and regarding Figure 9, it can be concluded that the 20% substitution rate is an optimal one and any additional substitution will cause considerable reduction in compressive strength.

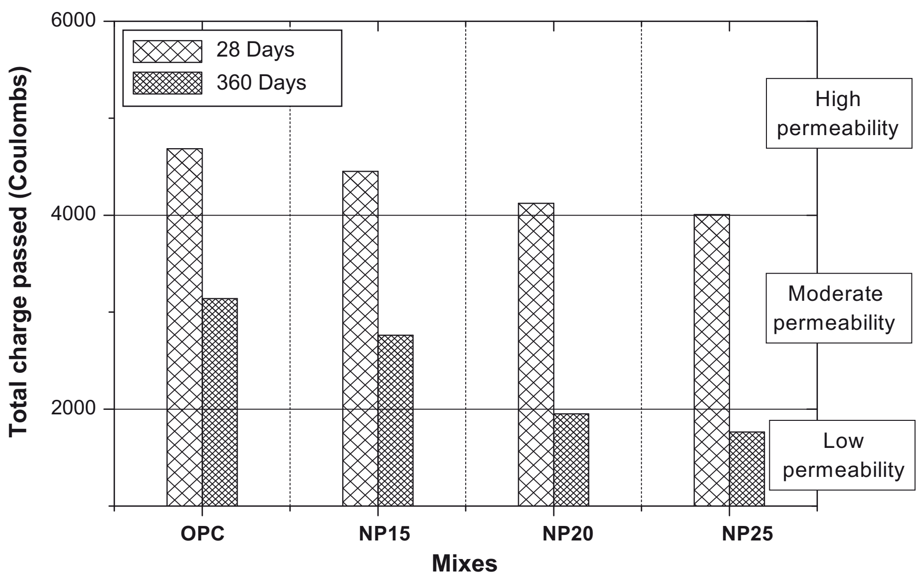

Figure 10. Chloride permeability of concrete mixtures at 28 and 360 days.

4.5. Rapid chloride ion permeability (RCTP)

The results of the rapid chloride ion permeability tests are shown in Figure 10. This figure also shows the chloride permeability classification according to ASTM C1202 (ASTM 1997). In all cases, the chloride permeability of mixtures containing natural pozzolan is lower than that of the reference mixture. In the period of 28 to 360 days of age all concretes show a reduction in permeability; the chloride ion permeability factor for plain concrete and concrete containing 25% of NP diminished from 4685 to 4005 coulombs and from 3140 to 1765 coulombs respectively. Thus, it can be concluded that, with regard to RCPT, the NP can be effectively used as partial replacement for cement, even up to 25%, in the production of durable concrete.

This may be related to the refined pore structure and the improved interfacial zone of these concretes and their reduced electrical conductivity (Al-Amoudi, Maslehuddin, Ibrahim, Shameem, & Al-Mehthel, 2011; Ozyıldırım & Halstead, 1994). Results reported elsewhere (Al-Amoudi et al., 2011) have shown a reduction in the chloride ion permeability with the addition of pozzolanic materials, with greater reductions obtained at higher replacement levels and lower water/binder ratios. These results indicate the beneficial effects of natural pozzolan, as a partial replacement for cement, in decreasing chloride ion permeability. According to ASTM C1202 (ASTM 1997), when the charge passed during a 6-hour period is between 1000 and 2000 C, the chloride ion permeability is 'Low'. This condition was satisfied only for specimens with 20 and 25% replacement levels cured for 360 days.

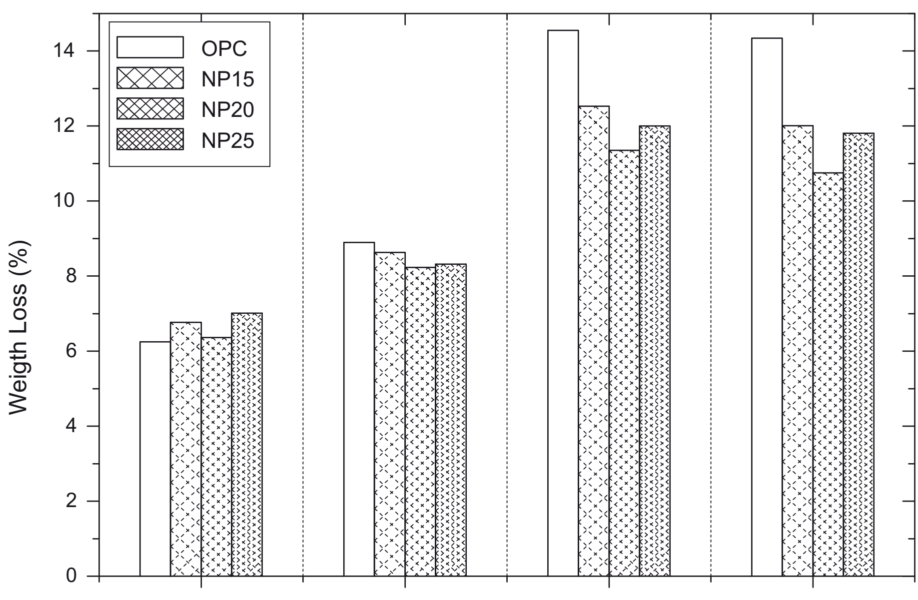

Figure 11. Weight loss of different mortar mixtures immersed in 5% HNO_3.

4.6. Acid attack

Figures 11 and 12 show the test results of weight change versus time for mortar specimens with and without NP exposed to 5% HNO_3 or 5% H_2SO_4 solutions for 1, 14, 28 and 56 days. There was a permanent percentage loss in weight with time for mortar blended with different levels of NP immersed in the different acid solutions. Before 14 days, the degraded thicknesses were of the same order of magnitude, and the differences between the four mortars were observed mainly after this age.

After this time of immersion, Figure 11 shows a variation in the rate of weight loss between the modified mortars (NP15, NP20, NP25) and the unmodified one. So, after 56 days' exposure to 5% nitric acid solution, all cement-matrix blended mortars corroded in acid solution more slowly than the control specimen of plain cement mortar. For the mortars containing 15%, 20% and 25% of pozzolan, the loss in weight was lower than that of the corresponding OPC mortar by 13%, 22% and 15% respectively (Figure 11). The chemical resistance to nitric acid attack of NP mortars could be attributed to the improvement in the bond between the hydrated cement matrix and the aggregate. This is due to the conversion of calcium hydroxide, which tends to form on the surface of aggregate particles, to calcium silicate hydrate (C-S-H). The effect of sulphuric acid on the mortar specimens is shown in Figure 12. Less deterioration was noted in the case of mortar with 25% NP. The loss in weight of mortar containing natural pozzolan in comparison with control mortar showed that all batches of pozzolanic mortar had lower mass loss than the control at the ages of 1, 14, 28 and 56 days. The decrease of loss in weight of the mortar due to addition of natural pozzolan can be attributed to the chemical properties and pozzolanic activity of the natural pozzolan of Beni-Saf (Algeria). These results are in good agreement with other studies in the litera-

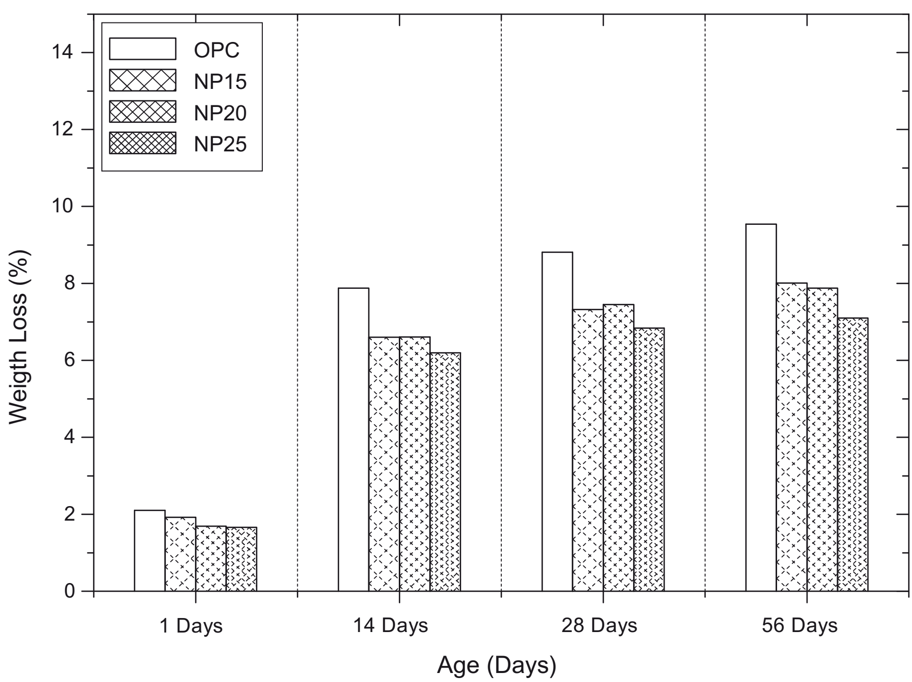

Figure 12. Weight loss of different mortar mixtures immersed in 5% H_2SO_4.

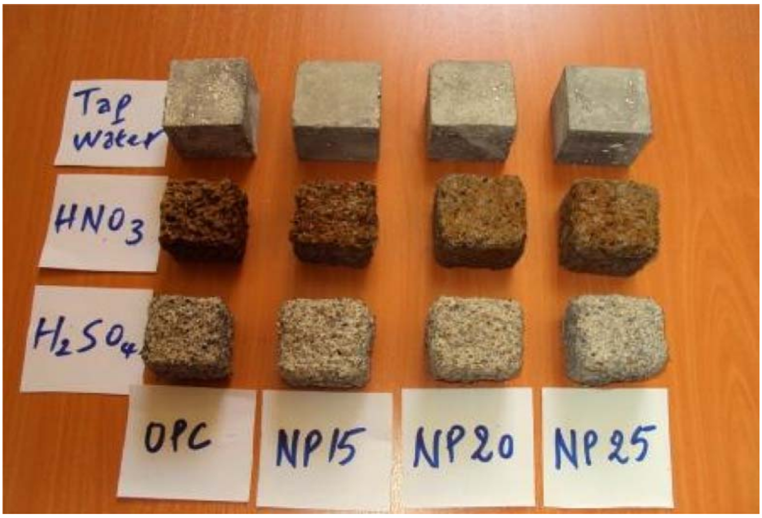

Figure 13. Deterioration of specimens after 7 weeks of immersion.

ture showing the beneficial effect of NP addition on the resistance of cement paste to leaching (Siad, Mesbah, Kamali Bernard, Khelafi, & Mouli, 2010; Uzal et al., 2007).

A visual inspection of specimens as shown in Figure 13 revealed the deterioration of the samples, particularly for the mortars immersed in nitric acid. These mortars kept their cubic forms more or less, but their dimensions decreased considerably. However, by comparing the aggressiveness of sulphuric acid medium and nitric acid medium, we conclude that, for the same concentration (5%), the overall degree of attack tended to be more severe in nitric solution than sulphuric solutions.

5. Conclusion

The experimental programme was designed to assess the effect of incorporating local natural pozzolan with ordinary portland cement on the properties of cement, mortar and concrete. Natural pozzolan addition considerably influenced some characteristics of cement. The following conclusions can be drawn based on the data obtained in this study:

- Natural pozzolan from Beni-Saf satisfies the criteria for natural pozzolans (class N), such as those of ASTM C618 (ASTM 2003), which requires minimum 7-day and 28-day Strength Activity Indexes of 75% and a minimum sum of the three main oxides (SiO_2, Al_2O_3, Fe_2O_3). One other result obtained from the Frattini test (in accordance with standard NF EN 196-5) indicates that finely ground NP is pozzolanically active and has the cementitious characteristics required to be used as cement additive.
- Substitution of natural pozzolan for cement increases the setting times because of the excess mixing water it needs and decreases the hydration heat of the specimens. This trend is intensified as the replacement level is increased. These results indicate the beneficial effects of natural pozzolan, as a partial replacement for cement, in decreasing peak temperature and the cooling slope, particularly in

large masses of concrete (e.g. dams), which results in a flattening of the thermal gradient and a reduction of the risk of cracking in massive concrete structures.

- The strength of pozzolanic cement is lower than that of plain portland cement at early ages. This strength difference decreases gradually in the following days and can reach the same order of strength at longer curing periods. The optimum dosage to obtain the maximum strength is 20% of NP.
- It is clear that chloride permeability resistance of pozzolan concrete is higher than that of mortar with portland cement. Also, the blended mortars with natural pozzolan addition have better resistance to the aggressions of sulphuric acid and nitric acid media than does the control mixture. This is important evidence that natural pozzolan can make a significant contribution to the durability of concrete.

Finally, by using these natural pozzolan resources in cement production, considerable amounts of heat can be saved and this can help to stop global warming and excess CO_2 emissions, which are the common ecological problems of humanity.

Recommendation for future work: this research needs to be supplemented by durability studies such as freeze–thaw resistance, permeation properties, carbonation resistance and activation of reactivity of natural pozzolans. Some of these tests are in progress.

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