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RESEARCH ARTICLE

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# Thermal Influence on Physico-Chemical Properties of Geopolymers Based on Metakaolin and Red Tomato Waste

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**The high amount of organic and inorganic wastes has increased the attention to new strategies aiming to reduce the waste disposals. Organic wastes, such as tomato wastes (TWs), are a good source from which the red color can be obtained. Among the different technologies, the geopolymers had been proposed as a powerful technology able to incorporate various kinds of wastes. In this paper, pure metakaolin and a mixture obtained by adding 10% of red TW-derived (peels) are consolidated by alkali activation at room temperature, 40 and 60°C without the pigment extraction. Fourier-transform infrared (FTIR) spectra confirmed the geopolymerization occurrences. Moreover, the obtained materials are analyzed for their conductivity and pH after the sample extractions at different times. The integrity tests assessed the resistance of the synthesized geopolymers and the presence of red tomato-wastes led to a release of yellow organic hydro-soluble compounds. Finally, the weight loss confirmed the integrity test. Indeed, there are no differences at 16 and 30 d.**

## 1. Introduction

In Italy – an average of 12 million tons of agro-industrial waste are produced every year, only the organic fraction reaches 9 million, but, at present, there is no established market for the reuse of this waste. However, many companies are implementing "green" policies with considerable foresight. To this end, they are carrying out projects with the aim of recovering molecules with high added value to be used not only to produce energy but also in the pharmaceutical, nutraceutical, cosmeceutical, and natural dye industries.

As a matter of fact, tomato peels contain pigments,[1,2] such as carotenoids, that have been extracted with various techniques[3,4] and to which remarkable biological properties are ascribed,[5–7] In addition to the fact that they could be used to color innovative materials such as geopolymers.

Geopolymers are low carbon binders obtained from the alkaline activation of natural minerals (clays), waste, or industrial by-products to generate a product with ceramic characteristics.[8,9] The aluminosilicate type reactive materials dissolve rapidly in an alkaline solution and form hydroxylated oligomers of the type $Si(OH)_4^-$ and $Al(OH)_4^-$.[10,11] During the polycondensation reaction, the tetrahedral units alternately join 2 to form amorphous lattices that make up the geopolymers. In recent years, geopolymers have gained much attention as binders with lower energy consumption and powerful characteristics including good mechanical properties, low liquid permeability, resistance to high temperatures, and acid attack among others[12] with a considerable reduction of $CO_2$ emissions, being more environmentally friendly materials.[13–16] In this paper, pure metakaolin (MK) and a mixture obtained by adding 10% of tomato peels waste-derived were consolidated by alkali activation at different temperatures. These materials have been characterized through Fourier-transform infrared (FTIR) analysis which demonstrates their geopolymerization. This study can be considered preparatory to a new line of research focused on the synthesis of geopolymers and the use of tomato waste (TW) as a natural dye.

## 2. Results

FTIR spectroscopy was used to evaluate the geopolymerization occurrence. **Figure 1** shows the FTIR spectra of MK, RTW, and the obtained geopolymers. The geopolymerization was followed by the shifts to lower wavenumbers (from 1080 $cm^{-1}$ of MK to 1016–1014 $cm^{-1}$ of the samples) of the density state of peak maximum (DOSPM), which refers to the asymmetric stretching of Si–O–T (T=Si or Al). These shifts confirm the formation of the

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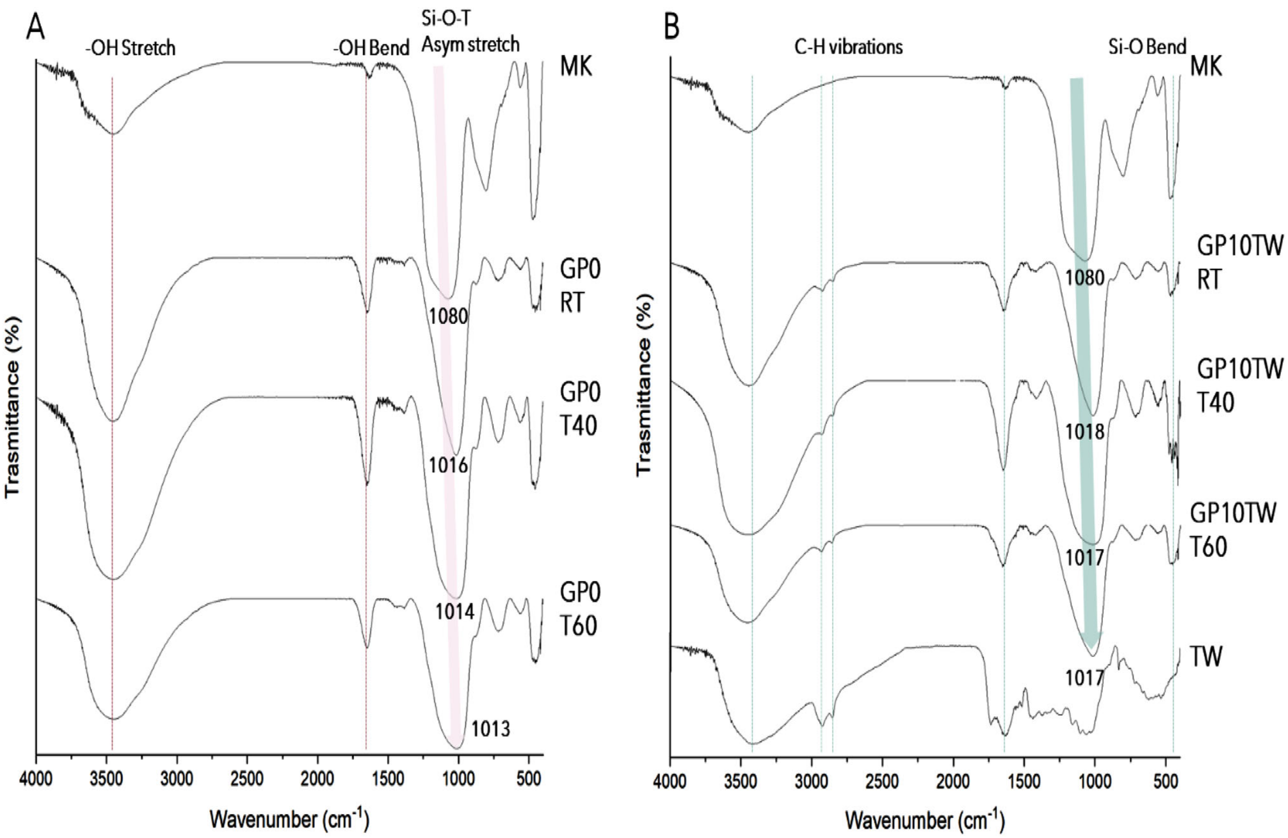


**Figure 1.** a) FTIR spectra of MK and GP0 cured at RT, 40 and 60°C after 30 d of geopolymerization; b) FTIR spectra of MK, TW, and GP10P cured at RT, 40 and 60°C after 30 d of geopolymerization. FTIR, Fourier-transform infrared; MK, metakaolin; RT, room temperature; TW, tomato waste.

3D networks for both the geopolymers with and without the organic waste.[13,17]

The stability of the synthesized geopolymers was assessed by evaluating the pH (**Figure 2a**) and the conductivity (Figure 2b) values of the samples extracted after 30 d of curing time. From the pH plot (Figure 2a) it is possible to notice that the pHs reach the stability, indeed after 48 h of measurement there are no significant differences. A stable conductivity of about 200 mS $m^{-1}$ (Figure 2a) was reached by all the samples, except the GP0 RT, which has a conductivity of 130 mS $cm^{-1}$ after 48 h.

The resistance of the synthesized geopolymers was assessed by means of the integrity tests, which consist of studying the ability of the material to avoid any cracks after 24 h in water. All the samples have not broken after the tests (data not shown), indeed there were not many weight differences before and after the test. This supports also the data obtained from the weight loss tests reported in **Figure 3**. Moreover, Figure 3 reveals that an increase of heat treatment led to a small increase of weight loss that is slightly higher for the geopolymers with 10 wt% of TW. This could be explained by the release in water, during both the integrity and the weight loss tests, of a yellow hydro-soluble compound.

## 3. Conclusion

Geopolymerization is a possible and promising technology for the management of large amounts of potentially hazardous or abundant wastes. In particular, tomato peels acting as a filler, treated at three different temperatures, do not show a high reactivity, besides they do not hinder the occurrence of geopolymerization of the MK precursor. This was confirmed by the FTIR analysis, which showed the formation of bonds between the two components. After 30 d, all the samples synthesized with 10 wt% of tomato peels showed a good geopolymerization and good physico-chemical characteristics as well as the samples obtained without the organic waste. The data obtained in this preliminary work are encouraging for the obtaining of new geopolymers that contemplate the use of waste from industrial tomato processing.

## 4. Experimental Section

MK (Argical-M1000), from Imerys, France, was used as the geopolymer precursor added with 10 wt% of red TW (sieved $x < 850$ μm). The precursor (100 g) was alkali activated with 30 mL of sodium silicate and 30 mL of NaOH 8 M. The pastes were poured into plastic molds and the setting phase was carried out at room temperature (RT), 40 and 60°C for 2 h followed by the hardening step at RT for 30 d.

Prestige 21 Shimadzu FTIR instrument equipped with a DTGS detector was used to evaluate the geopolymerization by using KBr pelletized disks (ratio mg of sample/mg of KBr = 1:100). The spectra were collected over a wavenumber range of 4000–

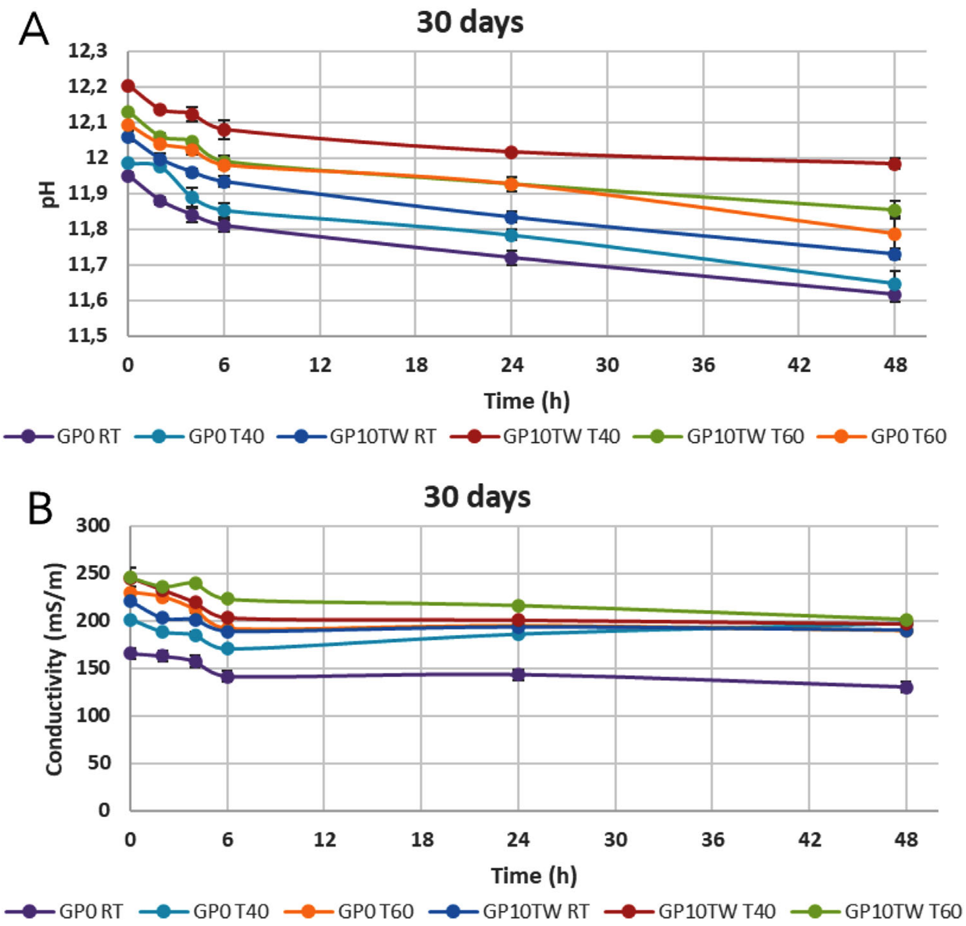


**Figure 2.** a) Conductivity and b) pH of the samples extracted after 30 d of curing.

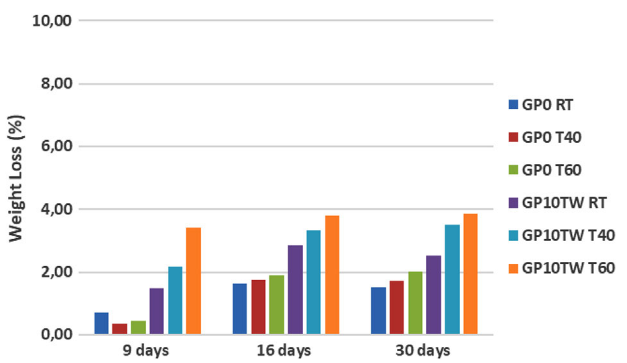


**Figure 3.** Weight loss of the geopolymers at 9, 16, and 30 d of curing time at room temperature (RT).

400 $cm^{-1}$ with resolution of 2 $cm^{-1}$ (60 scans) and they were processed by Prestige software (IR solution) and Origin 8.

Crison GLP31 and GLP21 were used to evaluate, respectively, the conductivity and the pH. The data were collected at different times (from 0 to 48 h) after the dissolution of 3 g of each sample (sieved $x < 125$ μm) in 30 mL of distilled water followed by the filtration (pore size 0.45 μm) under vacuum. Finally, the integrity test and the weight loss were carried out on the samples extracted at different time, by the protocols reported elsewhere in refs.[17, 18]

## Conflict of Interest

The authors declare no conflict of interest.

## Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

## Keywords

alkali activation, FTIR, geopolymer, metakaolin, organic waste

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