Infrared thermography study of historical bronze composition effects on the transport properties

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Bronze has always been one of the most popular materials for the manufacture of statues mainly because of its suitable metallurgical properties. In fact, bronze is durable and ductile, thus allowing the artist to more conveniently apply fine details to the statue after its main casting. In this respect, it is worth reminding that since ancient times it was used to appropriately introduce slight modifications in the alloy compositions to obtain low melting point, resistance to corrosion, color change for the insertions, etc. Therefore, the characterization of the bronze alloy composition of the different parts composing a given statue may allow one too gather valuable information about the process followed by the artist in the manufacture of the artefact, thus providing useful information for both scholars and restorers.

Presently, a large variety of experimental techniques is used for such a purpose among which Energy Dispersive X-ray Spectrometry, X-Ray Fluorescence, neutron-diffraction, involving complicated or expensive apparatus, or being not practical when applied to real artifacts. Among the non-destructive techniques applied to the investigation of cultural heritage items and, more specifically, of ancient bronze statuary, over the recent years active infrared thermography (IRT) has been proven to be a very effective tool. In particular, by means of such a technique it has been possible to both detect and characterize the workings undertaken after the main casting such the ones carried out to mend the openings occurred because of casting faults and the insertions. Finally, IRT has also been used for the evaluation of the local thermal diffusivity in ancient bronze statues. The thermal diffusivity, D, is known to be very sensitive to the bronze composition. Therefore, if the dependence of D on the concentration of particular elements in the alloy were known, its evaluation could lead to the determination of the concentration of such elements in the alloy. The knowledge of such a parameter is crucial for the quantitative characterizations of the geometrical characteristics of defects or insertions in ancient bronzes [1, 2].

In this study IRT has been applied to the measurement of the thermal diffusivity of specifically prepared bronze alloys containing different amounts of Sn and Pb, which are the major constituents in alloys used for the manufacture of ancient statues. Electrical conductivity measurements, linearly related to the thermal conductivity in metals, have been also carried out on the same set of samples to probe whether they followed a composition dependence similar to that of the thermal diffusivity.

Fig. 1 reports the values of D measured on the test samples, as well as some values reported in the literature as a function of C_{eff}, the total effective "weighed" concentration of Sn and Pb atoms. Here, the concentration of Pb was divided by a factor n to account for the known considerable smaller effects of the Pb than the Sn atoms to affect the transport properties in bronze, as observed for the electrical conductivity [3]. When such a procedure is adopted, with n=5.3, all the values follow a common trend characterized by a steep profile for the lower concentration range tending to saturate asymptotically for values exceeding approximately 10%. Such a trend could be fitted with the empirical expression:

$$D(C_{eff})= D_{Cu}e^{-\alpha C_{eff}} + B \qquad \text{Eqn. 1}$$

where D_{Cu} =1.15 cm^2/s is the thermal diffusivity value for pure Cu, obtained and α= 0.23 and B=0.08 cm^2/s. Such a curve can constitute a useful tool to determine the D value once the concentration in the alloy of tin and lead are known, and, perhaps, vice versa.

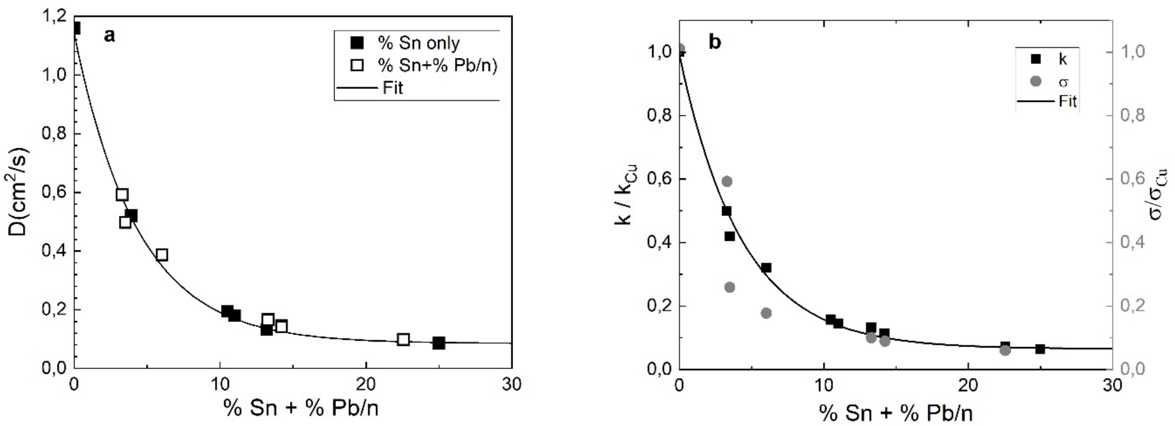

Fig. 1. (a) Thermal diffusivity as a function of the effective Sn+Pb/n weighed concentration with n=5.3 ; (b) normalized thermal conductivity, k, and electrical conductivity, σ, as a function of the effective Sn+Pb/n weighed concentration.

In Fig. 1(b), the values of both k, derived from D, and σ are reported, normalized to the respective values for pure Cu, as a function of the previously mentioned C_{eff}. It can be observed that the profile of both such quantities can also be reasonably well characterized by the same common trend previously reported for the thermal diffusivity. In fact, the reported continuous line.is obtained by the same expression as Eqn. 1, with the same value of α but with a different offset value.

References

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