Advances in Non-Destructive analysis of biodegradable Mg AZ31 magnesium alloys through pulsed laser thermography

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Abstract

The Mg AZ31 alloy, among biodegradable metallic materials, is a subject of extensive research for biomedical applications. This is particularly relevant in orthopaedics for temporary implants, aiming to avoid a second surgical intervention for removal. Its versatility extends to other sectors, such as the automotive industry, where it is utilized to produce casings and devices with an optimal compromise between lightweight and mechanical strength.

The growing interest in magnesium alloys is fueled by their ability to exhibit superplastic behaviour at high temperatures, making them suitable for innovative forming processes. The local treatment of these alloys, through methods like laser treatments, offers the possibility of obtaining precise mechanical characteristics tailored to subsequent processes [1,2].

Currently, evaluating the effectiveness of localized treatments relies on semi-destructive hardness measurements or metallographic tests. However, these tests present significant limitations, including irreversible effects on the component, the need to sacrifice samples, local verification of desired characteristics, times incompatible with company production rates, and difficulties in automation.

Non-destructive testing emerges as a promising solution to overcome the limitations of traditional techniques. Tomography, ultrasonics, and eddy current methods are recent approaches but have limitations such as significant time requirements, contact with the component, and challenges in automation. On the other hand, active thermography stands out as an appealing alternative: contactless, whole-field, and with analysis times compatible with industrial production, showing a greater predisposition to automation[3].

Moreover, in the literature, several studies have observed that, especially in steels, variations in microstructure, with composition held constant, correspond to different thermophysical and mechanical characteristics. Indeed, Mandelis et al. [4] have identified an anti-correlation between hardness and thermal diffusivity in certain materials. Other authors have utilized this principle [5] to obtain hardness profiles through the thickness. However, this result cannot be universally generalized to all metallic materials since each exhibits different mechanisms for varying mechanical properties based on the heat treatments they have undergone.

As for magnesium alloys, this correlation has yet to be observed and confirmed, representing the primary objective of the present work [6]. In the literature, various thermographic methods exist for measuring thermal diffusivity [7–10], each with its advantages and disadvantages. In the presented work, the pulsed laser spot thermography method was chosen to measure thermal diffusivity in different states of the magnesium alloy. A straightforward procedure was developed to be suitable for industrial process durations in terms of setup and testing times. This constitutes an initial step towards the potential industrialization of a dedicated system.

This study considered three specimens of Mg AZ31 with a thickness of approximately 1 mm, commonly used for formability tests. Two specimens were H-24 tempered, and one was O-tempered. One of the H24 specimens underwent annealing treatment at 450°C for 10000 s to promote grain growth in the alloy, achieving a uniform microstructure throughout the volume. Thus, three different conditions of the Mg AZ31 alloy were obtained: (i) O-tempered, (ii) H24-tempered, and (iii) H24-annealed.

The variation in microstructure due to heat treatment corresponds, as intended, to a variation in mechanical properties. However, grain size changes are expected to affect heat exchange capabilities, resulting in a variation in thermophysical properties. Based on this principle, pulsed laser thermography tests were conducted to measure thermal diffusivity, verifying a significant variation and its potential use as a non-destructive index for microstructure evaluation.

The described specimens were then subjected to a thermal experimental campaign, which involved performing pulsed laser thermography tests to measure thermal diffusivity and quantifying the percentage differences between the three material states analyzed.

Subsequent destructive tests of microhardness and metallographic analyses were conducted to confirm different properties and, importantly, to obtain quantitative indications of the mechanical properties of the analyzed specimens. This allowed for the establishment of a relationship between thermal diffusivity measurement and mechanical properties such as hardness and grain size.

Thus, a preliminary thermographic procedure based on laser thermography was developed for the quantitative estimation of mechanical properties of Mg AZ31, including grain size, in a completely non-destructive manner through thermal diffusivity measurement.

This preliminary study represents the first step in a larger project aiming to identify heat treated zones on a specific component. This would allow for an accurate measurement of treated regions and transition areas, providing a comprehensive map of the mechanical properties of the component in a complete non-destructive way.

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