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Microstructural characterization of a laser remelted coating of $Al_{91}Fe_4Cr_3Ti_2$ quasicrystalline alloy

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A bulk sample of Al–Fe–Cr–Ti alloy with adequate composition to form quasicrystalline phases has been surface remelted, using laser processing techniques, to produce a quasicrystalline surface coating. After the laser treatment, the samples were characterized by X-ray diffractometry, differential scanning calorimetry, scanning electron microscopy and scanning/transmission electron microscopy. The results indicate the feasibility of producing low-density coatings containing quasicrystalline phases by laser remelting on a bulk sample of an aluminum-based alloy.

Keywords: Quasicrystalline coating; Laser remelting; Surface coating; Al-based alloys

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Quasicrystalline structures can contain dislocations but the movement of these dislocations in the quasiperiodic structure, which is well-ordered but aperiodic, including icosahedral and decagonal atomic arrangements [1], is very difficult at room temperature because it causes the destruction of the quasiperiodic lattice [2]. This feature provides properties such as high hardness and low fracture toughness allied to high stiffness and low electrical and thermal conductivities. The brittleness of quasicrystalline alloys compromises their application as bulk engineering materials, but their low friction coefficient in combination with high hardness suggests their usefulness for wear-resistant materials applications, such as in the surface cladding of ordinary alloys [3].

Al-based alloys containing d-transition metals [4] are the most widely quasicrystalline compositions investigated to date, forming a quasiperiodic structure of three-dimensional icosahedral and two-dimensional decagonal quasicrystalline phases [5].

Many types of nanostructured quasicrystalline alloys have been developed in the last few decades, with microstructures consisting of nanometer-sized icosahedral particles embedded in an α-Al solid solution matrix. These alloys present high mechanical strength in comparison to nanocrystalline and commercial Al alloys and maintain it at high temperatures [6]. However, alloys are difficult to produce in bulk form due to the high cooling rates required to form the quasicrystalline nanoparticles (10^6 K s^{-1}), such as in melt-spinning or atomization processes. To attain these rates, rapid solidification methods must be used, e.g., spray-forming, melt-spinning and laser cladding. The high cooling rate prevailing in laser cladding [7–8] makes the process well suited for producing coatings containing quasicrystalline phases in many alloys and different substrates.

In this paper, we present results of the characterization of a coating produced by laser remelting of a bulk sample of $Al_{91}Fe_4Cr_3Ti_2$ alloy exhibiting quasicrystalline phase formation.

A bulk sample with a nominal composition of $Al_{91}Fe_4Cr_3Ti_2$ and dimensions of $22 \times 11 \times 15\ mm^3$

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was obtained using the spray-forming process. Its surface was remelted using a 2 kW CW Nd:YAG laser. The laser beam was transported by an optical fiber and focused onto a spot with a diameter of about to 3 mm at the surface of the sample.

Partially overlapped laser melting tracks were made using a laser beam scanning speed of 100 mm s^{-1} and a laser beam power of 1.4 kW. During the laser treatment the sample was protected by a static atmosphere of high-purity argon gas.

The surface of the coating was analyzed in a PHILIPS PW 3710 X-ray diffractometer with Cu $K\alpha$ radiation. Its cross-section was characterized by optical microscopy, using an OLYMPUS PMG3 inverted microscope and by scanning electron microscopy, using a JEOL 7001F field emission gun scanning electron microscope (FEG-SEM) with an Oxford X-ray energy dispersive spectrometer (EDS). The surface of the sample was observed in transmission electron microscopy (TEM) and scanning transmission electron microscopy (STEM) modes using a JEOL JEM 2100 HTP microscope operating at 200 kV coupled to a Noran X-ray energy dispersive spectroscopy (EDS) system. A JEOL JEM 3010 URP microscope (300 kV) was used to perform a high-resolution transmission electron microscopy (HRTEM) analysis. Image analysis was done using AnalySIS PRO software.

The thermal stability of the material was studied by differential scanning calorimetry, using a Netzsch model 404 DSC calorimeter at a heating rate of 40 K min^{-1}. For the DSC analysis, part of the track including the substrate was cut and the substrate removed by grinding. The sample's weight was 16.7 mg.

The coating obtained was 250 μm thick and 8.75 mm wide. Figure 1 shows the X-ray diffractogram of the sample's surface. The phases present are α-Al, Al_3Ti intermetallic compound and a quasicrystalline icosahedral phase. The same phases were observed by Yamasaki et al. [9] in $Al_{92.5}Fe_{2.5}Cr_{2.5}Ti_{2.5}$ alloy.

The DSC curve in Figure 2 shows an exothermic transformation at 554 °C, corresponding to the quasicrystal transformation, which occurs in a single step. This transformation temperature is similar to the one observed by Inoue et al. [10], who verified that this reaction was due to the transition from the I-phase to $Al_{13}Cr_2 + Al_{13}Fe_4 + Al_{23}Ti_9$ phases.

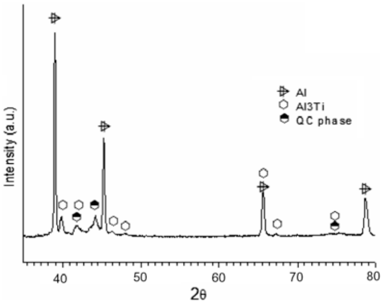

Figure 1. XRD results for the coating surface.

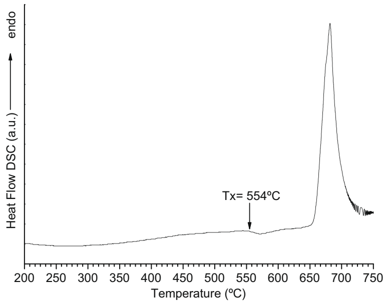

Figure 2. DSC result obtained for the coating region.

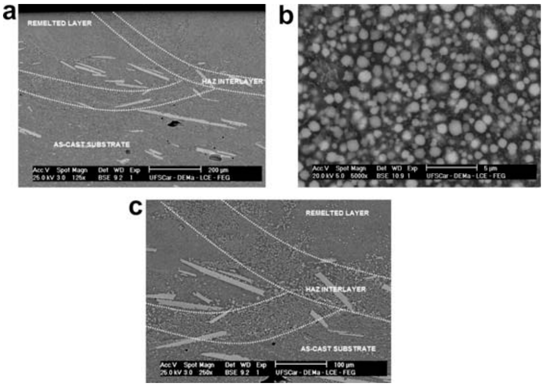

Figure 3. (a) Cross-section of the sample obtained by SEM-FEG indicating three regions: remelted layer, HAZ interlayer and as-cast substrate; (b) magnification of the center of a track and (c) region between tracks.

The SEM-FEG results in Figure 3 show spherical particles throughout the cross-section (Fig. 3a and b) of the individual tracks, with particle sizes ranging from 0.5 to 1 μm. No difference in particle size and distribution is visible along the cross-section. These particles consist of a quasicrystalline phase with Al–5.4 ± 0.1Fe–5.5 ± 0.1Cr–2.2 ± 0.1Ti (at.%) composition, as determined by TEM/EDS analysis, which is very similar to the composition determined by Inoue et al. [10]. The volume fraction of the QC phase is estimate to be 35% in the coating, larger than the volume fraction measured by Yamasaki et al. [9], who obtained only 8% of quasicrystalline phase using a rapid solidification powder atomization method. Two other phases are observed, one consisting of dendrites of aluminum solid solution and another, rich in aluminum and iron, at the grain boundaries. A large number of intermetallic phase particles were observed at the periphery of the tracks (region HAZ interlayer in Fig. 3a and c). This band presents a width of approximately 100 μm. These phases are observed in a region formed by the thermal influence of one track over the previous one during track overlapping, and their presence can create a brittle region in the coating. The particles may consist of Al_3Ti phase, observed in the X-ray diffractogram. However, no defects such as cracks were visible in this region and the large plates of Al_3Ti present in the substrate were seen only in the bottom region, indicating that this phase was not melted during the processing in this region.

Figure 4a shows a bright field (BF) transmission electron microscopy (TEM) image of $Al_{91}Fe_4Cr_3Ti_2$ sample in the center of a single track, with quasicrystalline (QC)