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EFFECT OF NANO-REINFORCEMENT ON PROPERTIES OF CAST Mg-Al ALLOY AZ91

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Abstract

In this study, nanocomposites based on magnesium alloy system AZ91 were fabricated by Semi-Solid Rheocasting (SSR) technique. Al_2O_3 (alpha) nanoparticles were added to the AZ91 alloy with different weight fractions. The results showed that Al_2O_3 nanoparticles could be mixed with AZ91 semi-solid slurry using mechanical stirrer technique. However, large clusters of nanoparticles were observed. SEM images also detected significant refinement the microstructural features due to the Al_2O_3 additives. Hardness tests showed that an addition of 2 wt. % Al_2O_3 nanoparticles resulted in 17% increase in the hardness. Corrosion tests indicated an improvement of 50% in corrosion resistance due to the addition of 2wt. % Al_2O_3 nanoparticles. Finally, mechanical dry wear tests revealed a 5% improvement in wear resistance for 2wt. % Al_2O_3 nanoparticles.

Introduction

Recently the new strategy in the automotive and aerospace industries is to replace the components which are made of heavy metals by components made of light metals with high strength to weight ratio property in order to reduce the fuel consumption and green house emission [1]. Accordingly, close attention is paid to light metals such as magnesium, due to its intrinsic characteristics of low density, good machinability and availability in the global market [2]. However the limitations of Mg and its alloys; such as low stiffness, high wear rate, high chemical reactivity, loss of mechanical strength at high temperature and creep resistance restrict the spread of the application of Mg alloys in automotive industries. So, the attention of researchers has been turned to engineered pathway metal matrix nanocomposites based on magnesium and magnesium alloy hopefully to find solutions to magnesium problems.

Faraji et al, produced a MMNC by adding (30 nm) Al_2O_3 nanoparticles with purity of 99 % in volume fraction of 8% to produce a nanocomposite layer on the surface of AZ91 by friction stir processing (FSP) [3]. The microstructure and the mechanical properties of nanoparticles reinforced AZ91 were also investigated by Nie [4]. SiC particles in 1 vol. % with an average diameter of 60 nm were introduced using the ultrasonic vibration device. While Gao [5] used ultrasonic waves to disperse nanoparticles and it was shown that it resulted ultrasonic cavitation based solidification for the AZ91/AlN nanocomposite. Shi-Ying [6] used both the mechanical stirring and high –intensity ultrasonic process to add 1.5% Multi-wall carbon nanotubes (CNTs) to AZ91 with greater than 95% purity and outer diameter of 20-40 nm and length in the range of 1-5 μm.
Qianqian et al [7] designed two-step process to achieve a good dispersion of the multiwall carbon nanotubes (MWNTs) in the AZ91 matrix. Firstly, dispersing MWNTs on the AZ91 chips; in this step, the agglomerated MWNTs were separate, then the MWNTS coated Mg chips were used to fabricate AZ91/0.1 wt. % MWNT nanocomposites by a melt stirring technique (with 370 rpm rotation speed for 30 min).

The previous review has shown that incorporation of nanoparticles to light metal alloys seems to be a challenging and promising ultimatum by material researches. Several methods have been explored by researchers [5-7], but using semi-solid processing techniques seems to need further exploration. However the successful trials of the research group at Cairo university [8-9], when the semi-solid process was used to add of Al_2O_3 and TiO_2 nanoparticles to Al alloy A356, encouraged the group to try to produce nanocomposite material based on AZ91 alloy and to investigate its corrosion properties.

The aim of this work is to investigate the prospects of using semi-solid casting to produce Al_2O3 nanodispersed Mg alloy AZ91, and to characterize and evaluate the properties of the new material

Experimental Procedures

Materials

Matrix: AZ91 magnesium alloy with chemical composition (in wt.%)of(9.3%Al,0.7%Zn,0.23%Mn,0.02%Si,0.001%Cu,0.001%Ni,0.002%Fe,0.0015%Be and balance Mg) is the most widely and commercially used Mg alloy system in the automotive industry. Therefore, it was selected as the matrix alloy during the current study.

Reinforcement: Alumina (Al_2O_3) nanoparticles (alpha with the average size of 80 nm were used as the reinforcement phase in this study. Figure 1 shows the SEM image of the as-received Al_2O_3 sample.

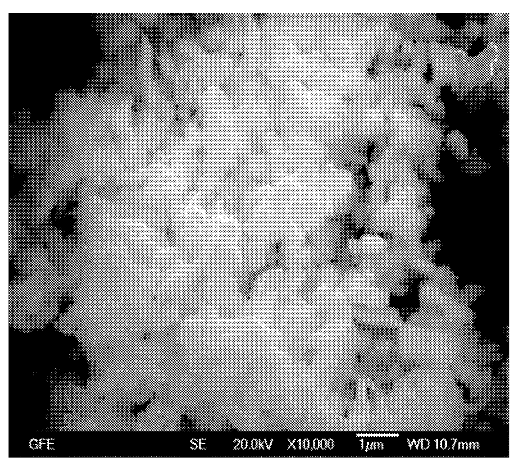

Figure 1. Morphology of Al_2O_3 nanoparticle

Fabrication Processing

The experimental setup that was used to reinforce the AZ91 matrix with the Al_2O_3 nanoparticles is shown in Figure 2. The fabrication process comprises several stages. First, the Al_2O_3 nanoparticles were wrapped in rod shaped packets wrapped in aluminum foil followed by heating up to 200 °C. Then, approximately 250gm of AZ91 were charged into the crucible until the temperature inside the crucible reaches 700 °C, in order to allow rapid melting and minimize oxidation during melting process. The melting process was carried out under a flow of gas mixture consisting of sulfur hexafluoride (SF_6) and carbon dioxide (CO_2) with CO_2+0.75%SF_6 (volume fraction) [5]. The AZ91 alloy was molten at 720 °C, and then cooled to 590 °C, which keeps the matrix alloy in the semi-solid condition [10]. Once the melt temperature reached 590°C, the aluminum foil containing Al_2O_3 nanoparticle was submerged beneath the surface of the melt. Afterwards, the melt was stirred mechanically using the four blade stirrers with a rotation speed of 1500 rpm for 1 min [8-9]. The mixture was then poured into a metallic die preheated to 200 °C using a tilt–casting system to minimize the turbulence. A reference AZ91 alloy was fabricated following the same aforementioned steps, but without the nanoparticles, in order to be compared with the reinforced samples.

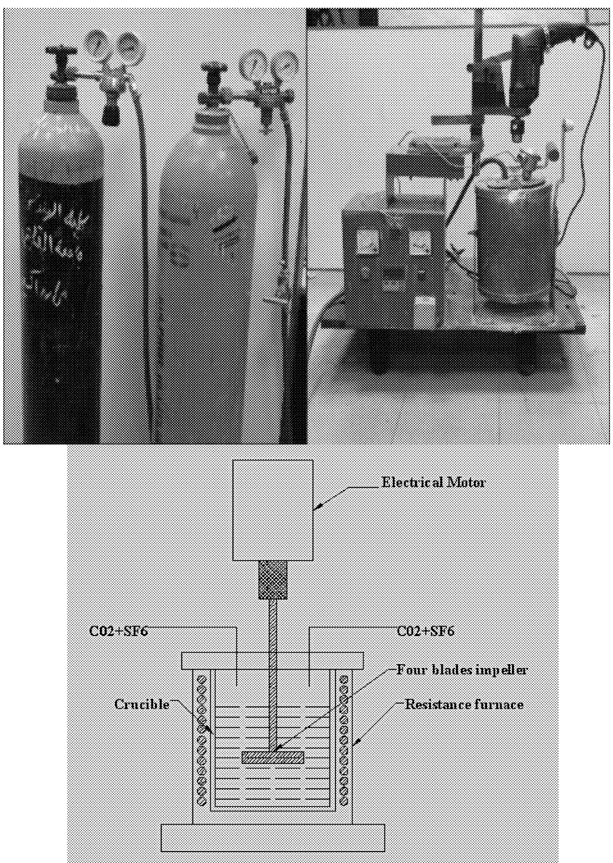

Figure 2.Mechanical Stirring unit used for the production of MMNCs.

Characterization Processing

The following steps describe the analyses of the AZ91/Al_2O_3 nanocomposites samples:

(1) The microstructures of the samples and the distribution of the Al_2O_3 in the Mg alloys matrix were examined by SEM (JEOL JSM-7000F) after the samples were polished using JEOL SM-09010 cross-section polisher.

(2) Hardness measurements were carried out on the polished samples. The microhardness was measured using Shimadzu-HMV automatic digital hardness tester while, the macrohardness tests were conducted on Brinell Rockwell hardness testing machine. The reported results are the average of five readings.

(3) Dry wear tests of the specimens were performed by a pin-on-disc test machine Test samples with 8 mm diameter and 20 mm length were cut and prepared from as-cast AZ91 and AZ91/Al2O3 specimens. The samples were tested under a load of 23N with speed of 1 m/sec for a total distance of 3600 m.

(4) Potentiodynamic polarization measurements were carried out using Volta lab 40 (PGZ 301) – RADIOMETER ANALYTICAL. All measurements were performed in freshly prepared aerated (3% NaCl) solution at room temperature.

Results and Discussion

SEM Observations

Nanoparticles Detection: As shown in Figure 3, nanoparticles agglomerations were found on the edge of the pores within the AZ91 matrix. Accordingly, this suggests that the nanoparticles were accommodated in the matrix. However, uniform distribution of the nanoparticles could not be achieved through the applied Semi-Solid Reheocasting technique.

Microstructure Observation: A selected number of specimens have been prepared using mechanical grinding and polishing technique to study the microstructure features and observe the nanoparticles. However, nanoparticles were not detected through this technique. The SEM micrographs of as-cast monolithic samples AZ91/0%Al_2O_3 and nanocomposite sample AZ91/2%Al_2O_3 are shown in Fig.4. It can be noticed that the grains of the matrix in the AZ91/2%Al_2O_3 nanocomposite were mainly refined by the addition of Al_2O_3 nanocomposite.

The microstructure of AZ91/0%Al_2O_3 cast in metallic die, shown in Figure 4, is characterized by α-phase in solid solution of aluminum in magnesium. A γ-phase was also found as massive intermetallic compounds with a stoichiometric composition of $Mg_{17}Al_{12}$, γ D-phase is an intermetallic compound with the same composition of γ-phase but in lamellar (discontinuous) morphology. This phase forms from supersaturated solid solution and α+γ partially divorced eutectic structure. It is clear from the comparison between the monolithic (AZ91/0%Al_2O_3) and composite (AZ91/2%Al_2O_3) that the eutectic phase is formed clearly and more uniform in a composite sample relative to the monolithic one. The eutectic structure is a very important feature that affects the mechanical properties.

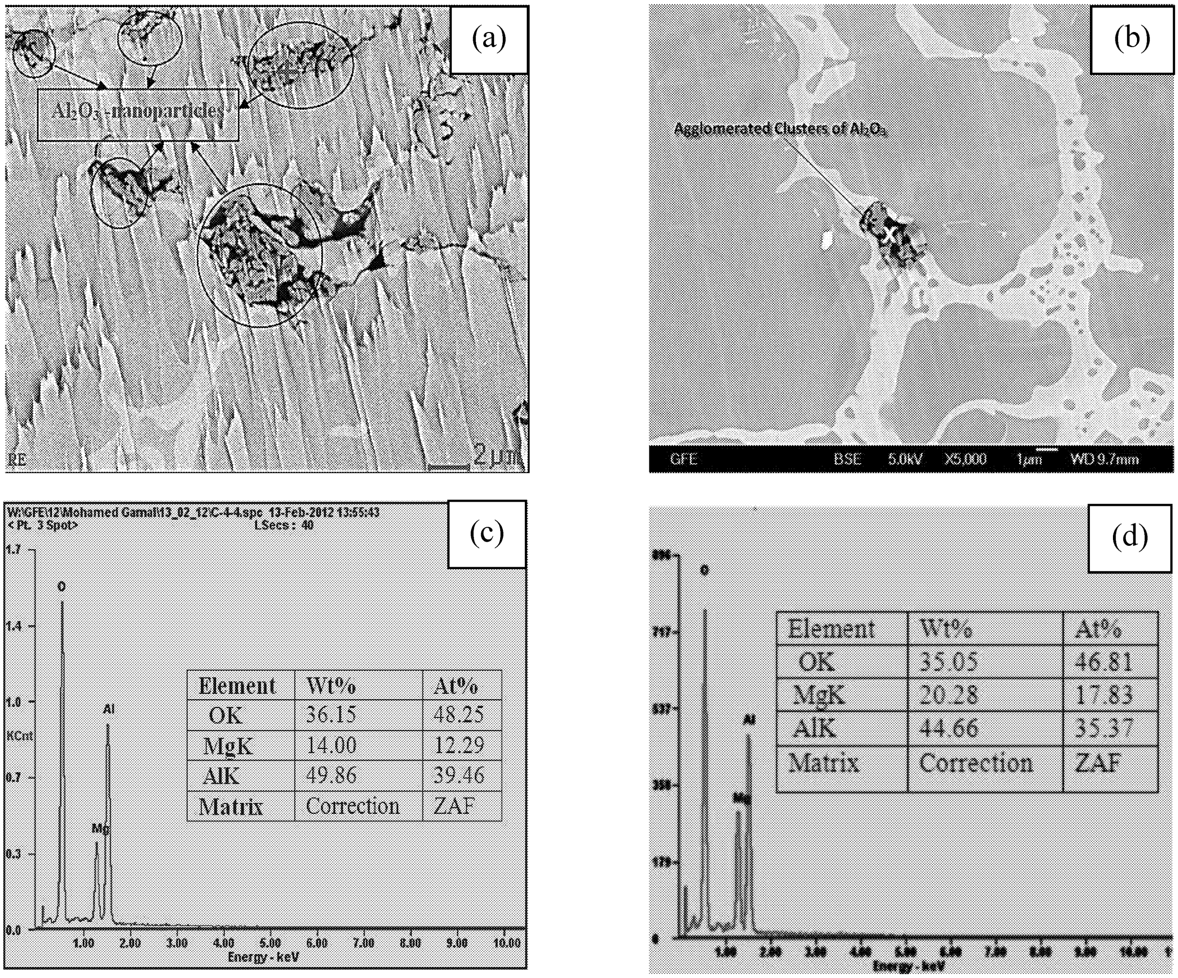

Figure 3. (a, b) detection of Al_2O_3 nanoparticles in two different position in AZ91/2wt.% Sample; (c, d) EDX of the selected area in (a , b) .

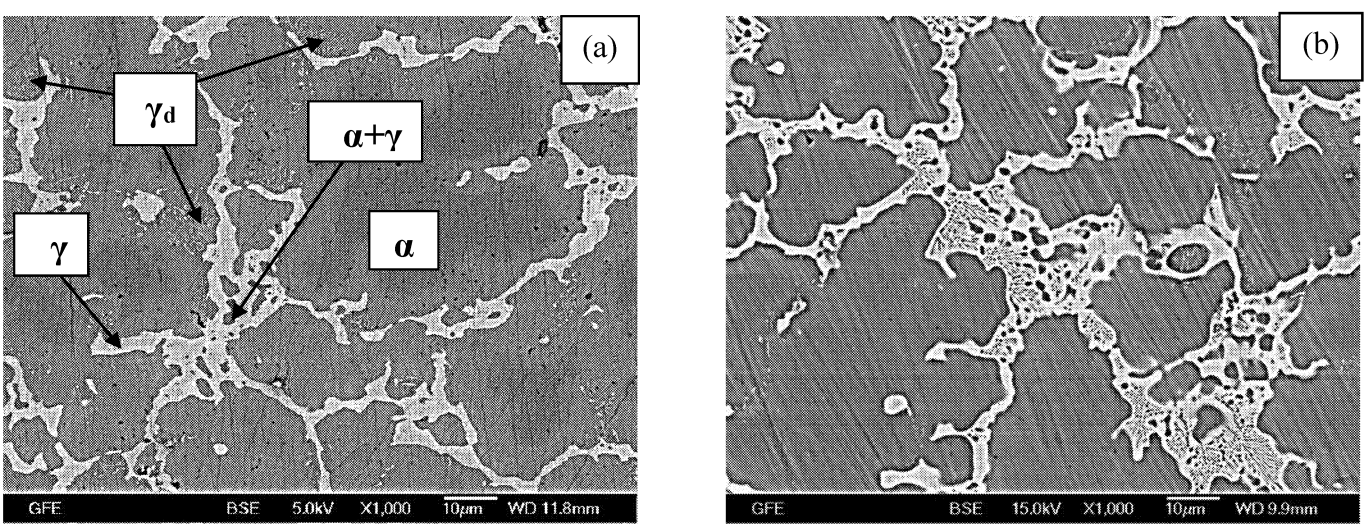

Figure 4. (a, b) SEM investigation of monolithic sample AZ91/0%Al_2O_3 and composite sample AZ91/2%Al_2O_3 respectively.

Hardness Results

Figure 5 shows a significant increase in both the microhardness and global hardness for the nanocomposite samples containing up to 3% Al_2O_3, in comparison with the monolithic sample AZ91/0%Al_2O_3. The microhardnes increase ranges from 7.3 to 30.5%, where the maximum increase was observed for the 1 % Al_2O_3. The global hardness results show that at 2% Al_2O_3 addition, the hardness increased by 17%.However, the results also show that a decrease in microhardness and global hardness occurred at 4% Al_2O_3 addition. The increase in the hardness of the nanocomposite samples in the present study can be attributed to: (1) the distribution of harder Al_2O_3 nanoparticles in the matrix, and (2) higher constraint to the localized matrix deformation during indentation due to presence of the Al_2O_3 nanoparticles.

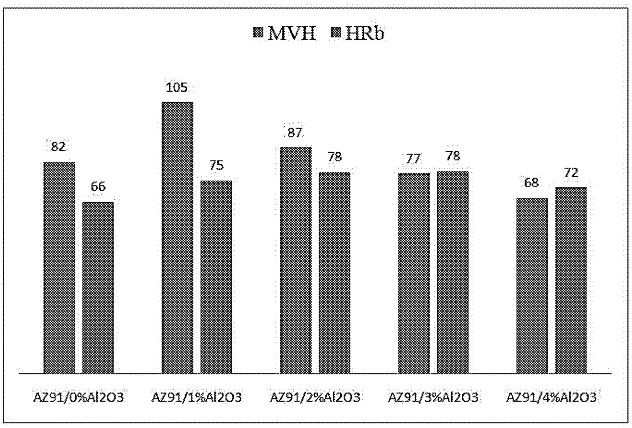

Figure 5. The effect of wt% fraction of Al_2O_3 nanoparticles on the HMV and Brinel hardness (HRb) of MMNCs.

Wear Test Results

Figure 6 shows the wear test results of the monolithic sample (AZ91/0%Al_2O_3) compared with the composite samples AZ91/[1,2,3,4%] Al_2O_3.The figure shows that the samples containing 2% Al_2O_3 exhibited the least wear (loss in mg). However the increase in the wear loss with the increase of the weight fraction of Al_2O_3 is in good agreement with the hardness results. The difference in the wear rates between the monolithic sample AZ91/0%Al_2O_3 and the nonocomposite sample (AZ91/2%Al_2O_3) which exhibited the least wear loss, as mentioned previously, is not significant (only 5.3%). This can be attributed to the agglomeration of the Al_2O_3 particles which causes a low integrity between the particle/particle and particle/matrix interfaces. This low integrity results in easy separation of particles from the matrix during sliding. On the other hand, these separated ceramic particles intensify the wear rate, since they act as abrasive particles between the disk and the pin.

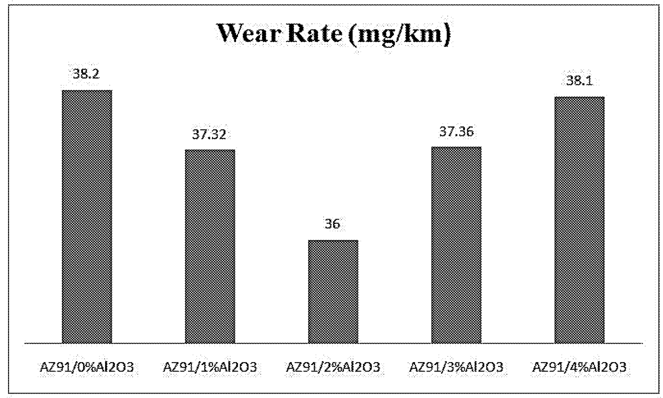

Figure 6. The effect of wt. % fraction of Al_2O_3 nanoparticles on wear rate of MMNCs.

Corrosion Test Results

Figure 7 shows the results obtained by the polarization test. According to the results, the AZ91/2%Al_2O_3 nanocomposite samples exhibited the least corrosion rate compared to the monolithic sample AZ91/0%Al_2O_3. In alignment with hardness and wear results, the corrosion loss also increased with increased weight fraction of the nanoparticles.

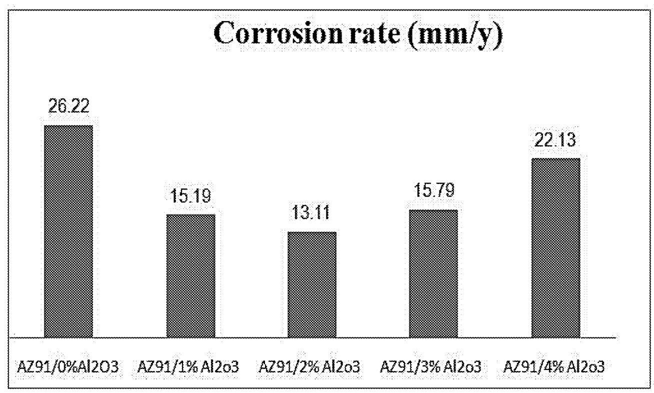

Figure 7.The effect of wt.% fraction of Al_2O_3 nanoparticles on Corrosion rate of MMNCs.

Figure 8 shows a SEM micrograph and EDX for the corroded surface of monolithic sample AZ91/0%Al_2O_3 and nanocomposite sample AZ91/1%Al_2O_3. It is clear that the pitting is observed on the corroded surface of the monolithic sample, whereas it is not observed on corroded surface of the nancomposite sample. Therefore, it can be understood that the additions of Al_2O_3 nanoparticles help to prevent pitting corrosion mechanism.

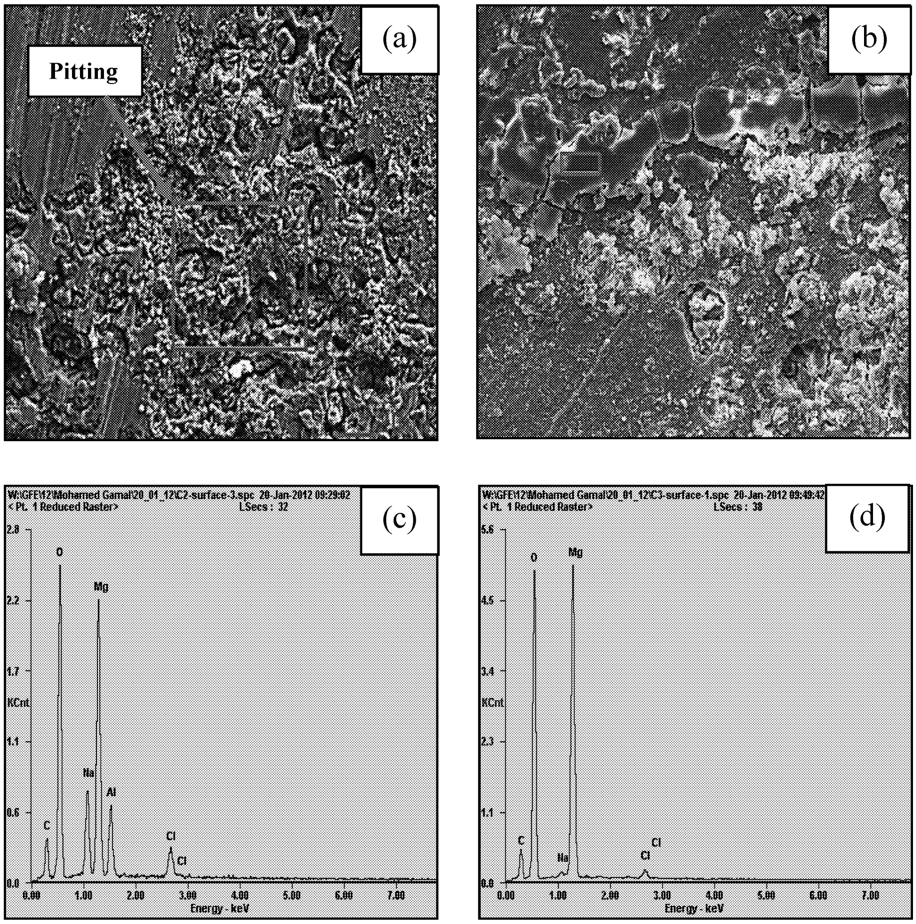

Figure 8. SEM micrographs for the corroded surface of (a) AZ91/0%Al_2O_3 and (b) AZ91/1%Al_2O_3 ; and (c) and (d) EDX analyses of selected regions in (a) and (b).

Conclusions

From this study we can conclude that:

(1) Semi-Solid Rheocasting (SSR) technique was applied to prepare MMNCs based on AZ91 alloy.

(2) Mixing the Al_2O_3 nanoparticles with AZ91 semi-solid slurry using mechanical stirring technique was used in this work, but SEM images showed that this technique does not lead to the achievement of a uniform distribution of the nanoparticles.

(3) SEM images detected significant grain refinement for the (AZ91/Al_2O_3) matrix, in addition to the formation of eutectic phase which was enhanced after the addition of Al_2O_3 nanoparticles, which leads to improvement of the mechanical properties.

(4) The results of the hardness test, wear test and corrosion Test show a significant improvement on some of the sample which contain nanoadditions.

(5) Adding nanoparticles up to 2wt. % Al_2O_3 exhibits the best results for all the tests. For 2wt.% Al_2O_3, hardness results showed 17 % increase in hardness, wear results showed 5% increase in wear resistance and corrosion test shows 50% increase in corrosion resistance.

(6) Increasing of the weight fraction of Al_2O_3 nanoparticles may be attributed to the accompanied increase in the slurry viscosity, resulting in the inability of the mechanical stirrer to disperse the nanoparticles, which ultimately leads to agglomeration of the nanoparticles.

Acknowledgements

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