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Effects of thermal treatment with CO_2 laser on the structure and the hardness of compressed aluminum samples

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Abstract : In this research, samples of aluminum was prepared using the compression and annealing methods. Continuous CO_2 laser and thermal heating in suitable oven were used for annealing procedures. FT-IR spectroscopy was used for prepared samples description. Mechanical hardness properties were measured using hardness tester.
Results conclude that the surface layer is oxidized in different levels depending on both, the method and the time of treatment. Two different phases of aluminum oxide were noticed which are Amorphous (non-crystalline) and Gamma phases. Moreover the important structural changes were observed when using time intervals bigger than 10s. Annealing using thermal oven did not provide quick structural changes like when the laser was used, but it led to higher mechanical hardness and less structural defects.
Key Words: Aluminum, Compressed, Annealing, CO2Laser.

1.Introduction

Aluminum is a chemical element with symbol Al, and atomic number 13. It is a silvery-white, soft, nonmagnetic, and it could bee asily shaped [1-3]. Aluminum could be forged as thick plates for heavy industries or pulled as thin sheets for food packaging. It is also used in airplane manufacturing due to its light weight[1]. It does not corrode and it is resistant for erosion under atmospheric conditions or chemical reactions. Aluminum is the third most abundant element in the Earth's crust (after oxygen and silicon) and makes up about 8.3% of the crust by mass[1]. This metal is highly chemically reactive to oxygen that individual specimens could not be found. On the contrary, it is found combined with oxygen and silica in rocks and Earth’s crust[1].

Aluminum oxide Al_2O_3 is a chemical compound known as alumina. It has two different forms (alpha and gamma) with different crystal structures[1-3]. They are different in chemical and physical properties and they are also used in different applications. Aluminum oxide gained the attention of many research groups[1-13].

The procedure of powder metallurgy is as following[1]:

1. Preparing metal powder and mix it.
2. Compressive forming of the powder using solid and highly resistant mold to get the required shapes. During this process, the spaces between the powder particles decrease and they partially solidify.
3. Sintering the compressed product by heating the samples to relatively high temperatures, but less than melting temperature of either the powder or the compounds. Sintering leads to higher solidification of the powder particles causing increase in the density and hardness of the product. Suitable sintering temperature and enough time should be chosen correctly to get high quality product.

Valence electrons in any conductor act like free electrons, where the collision among the electrons is similar to that one that occurs between gas molecules which is described in kinetic theory of gases[14,15]. Optical properties of metals are produced because of the interaction between the fallen photons on the surface and the electron cloud[14,15]. Optical reflectivity is considered as the most important physical property of metal layers, it basically relates to the interaction between the light and free electrons which could be expressed by dispersion equation as follows [14,15]:

$$\varepsilon_f = 1 - \omega_p^2 \Big/ \left(\omega^2 - i\omega/_\tau\right) \qquad (1)$$

Where ω_p is plasma edge, it is a unique feature of metals expressing plasma-resonance frequency of free electron, τ is the relaxing time,ω is a light frequency. Both electrons density and effective mass affect this plasma edge (5) and could be determined directly from reflecting spectra where chronic changes of reflectivity happen at plasma edge as a result of electrons drag difference[14,15]. Further more, shifting of plasma edge towards higher wavelengths means increasing the free charge holders (5).

2.Experimental Procedures

Compressive forming of high purity aluminum powder (99.98%) was done using hydraulic compressor. The applied pressure was 70 KN. Cylindrical samples were obtained with diameter 1.25 cm, the thickness is 2.1 mm, and the weight is 0.7 g. To get rid of any fat or unwanted materials, the outer surface was cleaned using alcohol.

Part of these samples treated thermally by50WcontinuousCO_2 laser beam for several time intervals (10, 20, 30, 40, 50s). The rest were also treated thermally but this time by heating them to 400 C° using thermal oven for several time intervals (2,4,6,8hrs.). Finally, all samples were described, mechanical hardness test was done by hardness tester MHT-10Microhardness Tester and FT-IR spectra were recorded using spectrophotometer.

3.Results and discussion

Figure 1 represents FT-IR spectra for two samples, the first one is not thermally treated, but the second one is treated by CO_2 laser for 10s.

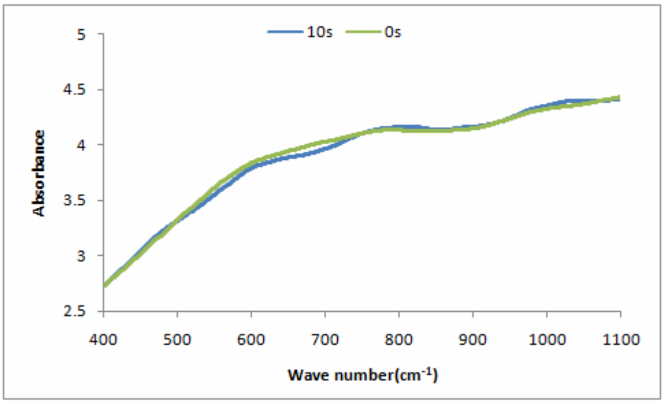

Fig. 1 FT-IR spectra for two samples: the first one is not thermally treated, the second one is treated by CO_2 laser for 10s.

It is observed that the two spectra are almost identical, thus thermal treatment for 10s did not affect properly the structural composition. Three basic peaks could be distinguished.

When longer time intervals were used (Figure 2), the follows were noticed:

1. Different spectra were obtained comparing with those in Figure 1.

2. Absorption was decreasing with the increased of wavelength, and this is completely opposite to the described conditions in Figure 1 previously.
3. The spectra peaks were the same as those in Figure 1.
4. The most important difference among spectra in both Figure1 and Figure 2 were the wide intensity range in both cases. Intensities of spectra in Figure1 are ten times higher than those in Figure 2.

The reason of this wide range of intensities (a, b samples states) Figure 1, is probably caused by the existence of deoxidized aluminum which composes high ratio of the sample surface layer composition, so the intensity will increase because of the increasing of the interaction between IR and plasma.

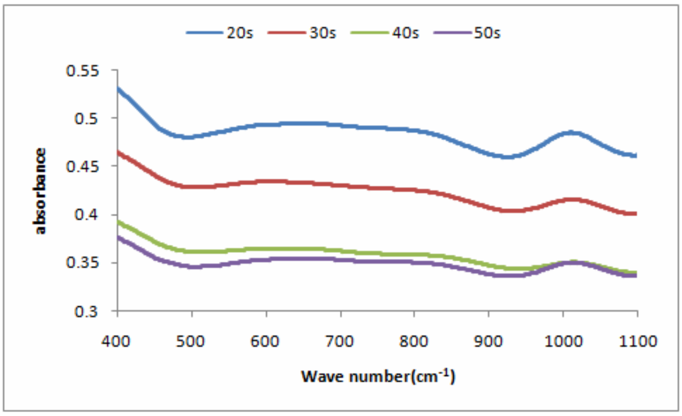

Fig. 1 FT-IR spectra for samples with longer time intervals.

When the treatment time is increased the ratio of oxidized aluminum is increased as well, causing different combinations of aluminum and oxygen (Al-O, O-Al-O, etc.) that lead into decreasing the deoxidized metal in the sample surface layer composition and decreasing the interaction intensity between light and plasma.

Figure 3 illustrates the peaks amplitude as a function of treatment time. Decreased intensity was observed for each peak with treatment time. This decreasing does not mean decreasing in proportion of different combinations of aluminum and oxygen for each peak, but respectively means decreasing the interaction intensity between light and plasma as a result for the decreasing of the non-interacted metal density through the surface layer.

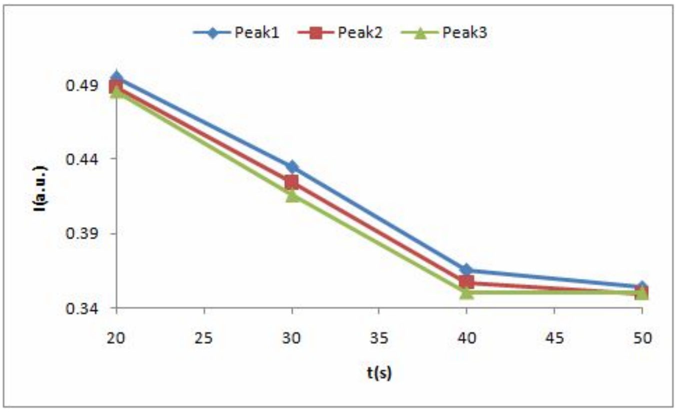

Fig. 3 peaks amplitude as a function of treatment time.

Figure 4 represents the shifting positions of peaks amplitude versus treatment time. All peak's shifting positions were toward the higher wavelength's numbers, which are considered as a proof for increasing the content of oxygen in the sample.

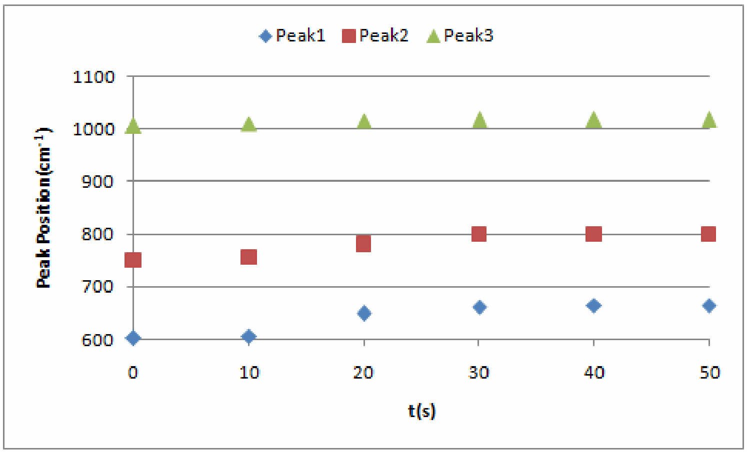

Fig. 4 peaks position as a function of treatment time.

It is useful to compare the effects with another used procedures. Figure 5 is shown this comparison between laser's treated sample for 10s and a thermally treated sample in oven for three hours at 250°C. Oven thermal treatment acceptably reduced the interaction between light and plasma comparing with another sample, but its affectivity was less comparing with laser treated sample at higher treatment time.

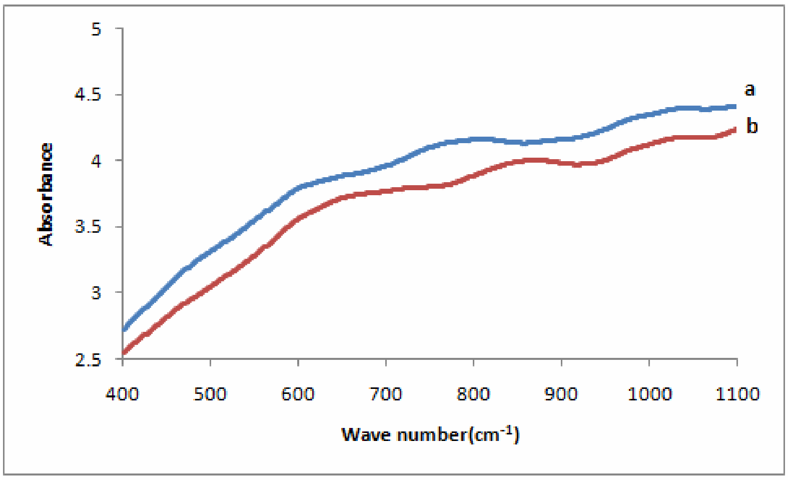

Fig. 5 FT-IR spectra for two samples: the first one is laser's treated, the second one is Oven thermal treatment.

Thermal treatment affects obviously on the mechanical properties of the material. Figure 6 shows big changes in mechanical hardness versus treatment time with CO_2 laser. Lower values of hardness were noticed with increasing treatment time. This could be explained that this type of treatment caused damages in material structure and increased the structural defects because of thermal stress.

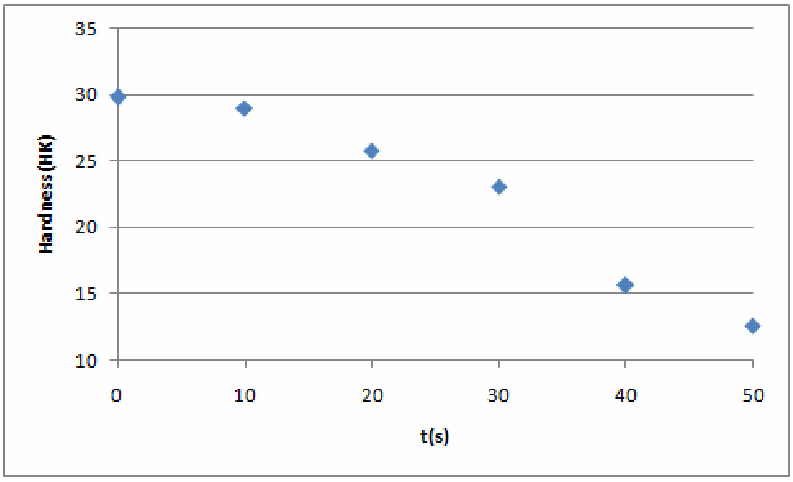

Fig. 6 hardness as a function of treatment time.

Regarding another sample which is treated by thermal oven, the hardness value was 40.7HK and it is the highest value among the all values has shown in Figure 6. That indicates the oven thermal treatment provides lower ratio of defects and structural damages.

4. Conclusion:

Results in this research indicate that thermal treatment of aluminum samples reduced interaction intensity between light and plasma. This research were effectively using continuous CO_2 laser treatment, but less affectivity when oven thermal treatment was used that contributes to stronger structure.

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