Production of Aluminum Matrix Composite Material by Active Carbon Additive

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Research Article

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Abstract

The effectiveness of composite materials with the addition of activated carbon produced from biomaterial with a new application on aluminum-based composite materials was investigated in this study.

Activated carbon was produced from the peanut shells via the chemical activation method and the obtained activated carbon was mixed with aluminum and composite material. For the characterization of the composite material obtained, XRD and SEM-EDS optical photographs were assessed in the experimental process. According to Vickers Hardness and Dynamic Micro Hardness results, the sample with the hardness value of 2% AC added had the highest hardness value. The elastic modulus values was found to increase by 3.4 times (9.59GPa) compared to aluminum with the addition of 2% activated carbon. This increases with activated carbon quantity, and weakens the matrix structure due to weak van der waals interaction with aluminum, which reduces hardness; therefore, the best ratio of the activated carbon reinforcement to the aluminum matrix was obtained at 2% activated carbon addition.

1. Introduction

Aluminum and aluminum composites are used very frequently in areas such as automotive, aerospace industry due to their properties such as high thermal and electrical conductivity and good corrosion resistance[1]. The utilization of aluminum composites in aerospace industries has increased due to their lighter weight [2]. Increasing demands for light-weight materials for improving the efficiency of vehicles is the main driver behind the current research and development of aluminum composites [3]. Metals having a reduced specific gravity have useful mechanical characteristics including strength, which provides the required strength with less weight, and thereby reducing fuel and operating costs. They have high electric and thermal conductivity, high damping capacity, and high corrosion resistance [4]. AMCs have created interest in research communities since 1920s [5]. One of the main reasons to conduct the current research was to find out which material is appropriate for composite preparation. Since it is a metal matrix composite, we had several options to fill up the slots of the matrix and several options for reinforcement materials. The next task was composite preparation. To prepare that, the reinforcement and method type have to be decided beforehand [2]. We focused on the materials which have contributed to the aircraft industry and in the developments in metal matrix composites; therefore, we chose aluminum as our matrix material. Various research is still ongoing on analyzing multi-faceted characteristics of aluminum. Besides the contributions of aluminum to our industry in the previous years also made a key point in selecting it, selecting the reinforcement was a different task, for which we had to know how to mix both the materials and type of reinforcement to be used,[2, 6]. Thus, composite materials, particularly metal matrix composites, have taken aluminum's place due to the enhancement of mechanical properties of aluminum alloys via reinforcements. Thus, composite materials' major benefits include their strength, which is very useful to improve the structural performance of spacecraft and military equipment. Mechanical characteristics and the wear resistance of Al 7075 graphite composites were studied during research [7], into carbon-reinforced aluminum composites [8] and characteristics and microstructures of

Al_2O_3, SiC, and B4C, reinforced Al [9]. Activated Nano-composites of carbon were used with alumina. It was synthesized and applied to remove sulphide ions from water[10]. Wear behavior and physical properties of aluminum have been discussed along with palm shell activated carbon[11]. We utilized reinforcement in particulate form, which suits the composite preparation technique, and reinforcement was nothing other than activated carbon. Activated carbon was produced via a slight modification to carbon, after which, carbon remains in a stable form[9]. For economic reasons, and as it is a renewable source, agricultural by-products and waste materials have been explored fo actived carbon production for a long time[12]. Activated carbon has some excellent properties, which exist in active form: it can be highly porous, shows higher absorption rates, possesses the capacity to bind substances using London dispersion force or Van der Waals force, exhibits higher absorption rates, shows more reactivity than carbon, prevents corrosion and plays a significant role in gold, water, and gas purification processes, air filtration, and metal extraction[13]. Processing results in additional surface area for chemical reactions or absorption[14]. The reinforcement multi-walled carbon nanotubes are added in the various ratios between 2–10% weight of AA6061 alloy[15]. According to our knowledge, aluminum composite materials with an aluminum matrix and with aluminum composite materials containing activated carbon are not available in the literature, although there are many studies in the literature where carbon nanotubes are used in this manner.

The objective of this work is to assess the aluminum matrix reinforcement using activated carbon obtained from vegetable waste, the new type of composite material obtained and then to use activated carbon as reinforcement with a porous aluminium matrix composite material made by powder metallurgical with improved performance, for example mechanical properties, with focus on the mechanical testing such as hardness, density and microstructure tests such as SEM, EDS and XRD.

2. Materials And Experimental Setup

2.1. Preparation of activated carbon

Activation of activated carbons used in experiments was performed by mixing 5 M 250 ml HNO_3 and 50 g powdered peanut shells, after which it was left at room temperature for 1 day to remove structures outside the carbon skeleton of the peanut shells. Then, the samples were dried in the oven at 105^oC for 1 day and were pyrolyzed in a stainless-steel closed reactor vessel at 800^oC for 2 hours under a constant flow of N_2 nitrogen for 2 hours. The samples were then left to cool under a constant N_2 nitrogen flow. The cooled samples were removed from the reactor and subjected to washing with a 1 M NaOH solution to neutralize the excess of HNO_3. Afterwards, the samples were washed 3–4 times with warm distilled water and dried in the oven at 110^oC for 1 day. The dried samples were grinded again in the grinder and sieved through the sieve to bring the particle size to 0–50 μm.

Table 1
Activated carbons bet surface area and other properties

Samples	Bet Surface area (m^2/g)	Weight % C	Weight % O	Weight % Al
Raw Peanut shell	0.83	29.9	22.5	0
Activated Carbon	82.9	55.07	10.67	0
Al+ %2 AC		2	0	98.00
Al+ %4 AC		4	0	96.00
Al+ %6 AC		6	0	94.00

Table 2
Experimental and relative densities of Al / Activated carbon composites

Sample	Experimental density (gr/cm^3)	Theoreticaldensity (gr/cm^3)	Relative Density (%)
%2AC + Al	2.44	2.65	92.21
%4AC + Al	2.30	2.59	88.80
%6AC + Al	2.28	2.54	89.69
Raw Al	2.43	2.70	90.00

Table 3
Changes of elastic recovery dynamic stiffness and elastic modulus of composite material with addition of activated carbon

Samples	Elastic recovery Rate(h_{max}-h_f) (μm)	dynamic stiffness (GPa)	Elastic Modulus (GPa)
Al	17.5	0.056	2.77
Al+%2 AC	7	0.16	9.59
Al+%4 AC	14	0.12	4.95
Al+ %6AC	13.3	0.10	4.40

2.2. Preparation of activated carbon-aluminum composite

The matrix material Al and AC were applied as additives. Aluminum powder with 99% purity with on average particle size of 17–30 μm has been used in the current study. The composites were prepared by mixing aluminum with activated carbon by mechanical alloying. The mechanical alloying was conducted using a PM 100 Retsch planetary ball mill. The mill consists of a steel vial with a 60mm depth and 100mm diameter cylindrical cavity. For milling, nine small steel balls were selected, which each had a 12mm diameter. They were selected to strengthen the metal bonds. 150 rpm was the rotational speed of milling. The vial contained 100g of powdered mixture and steel balls, which was sealed in a pure argon atmosphere. The first batch of composite powders was Al and AC-based with the composition of: Al-2wt

%AC, Al-4wt %AC, and Al-6wt %AC. The mixture was placed in a storage tube so as to lose contact with air and oxidization. Finally, the Al-Active carbon composite material was obtained using a metallographic sample preparation method. The powder mixture was loaded in a cylindrical mold with an inner diameter of 13 mm, and the powder was placed under 500 MPa. On a quartz tube, a circular disk was loaded in a MTI GSL-1100X-S50 furnace. When the protective argon gas was supplied to the specimen, the temperature was increased to 550°C. This sintering temperature required almost 1 hour waiting time. The specimen was later naturally cooled down. The resulting composite pellet keller solution (190ml pure water + 5ml HNO_3 + 3ml HCl + 2 ml HF) was etched.

3. Characterization Of Activated Carbon And Composite Materials:

The composition of the material was determined using the energy X-ray spectroscopy (EDS) technique, and the kiss images of the samples were obtained with a Olympus GX41 device. SEM images were obtained by a FEI QUANTA 250 FEG scanning electron microscope.

The stiffness of the composite is due to strengthening of particle reinforcements with a low aspect ratio. The ASTM E10 standard is used to test hardness. The Brinell test was adapted to find the metal hardness. A ball type intender with 10mm diameter is applied at 5N load.

For determining sample hardness through hot pressing, the sample hardness was measured with the help of a Brinell hardness testing device at 62.5 kg load with a 2.5 mm ball diameter. For completeness in determining hardness, the measurement of hardness values was initiated from the samples' middle, tip, center, and rear side, using a total of 3 values of hardness for each sample. Later, the lowest and the highest were removed, and the average hardness values was determined, taking the average of remaining values of hardness.

The aluminum matrix composites' densities were calculated with the help of a QUANTACHROME and ULTRAPYC Model 1200E helium pycnometer. The Ultrapyc 1200e is a gas pycnometer that accurately measures the volume and density of catalysts, powders, drugs, carbons, ceramics, rock core plugs, and building materials. The density was calculated and applied to the lower part of the bolstered samples and metals. We selected the Archimedes principle, which is a density measurement method. Archimedes' principle was applied to find the results, which are expressed through the following expressions for composites' densities.

Density of activated carbons:

$$\rho_{AC} = \frac{W_o}{V_p - \frac{W_t - (W_p + W_o)}{d_s}} \qquad [1]$$

Volume of activated carbon:

$$V_{AC} = V_p - \frac{W_t - (W_p + W_o)}{d_s} \quad [2]$$

Where;

Weight of pycnometer: Wp

Weight of activated carbon: Wo

(Pycnometer + Activated carbon + Liquid): Wt

The density of pure liquid: ds

The volume of pycnometer: Vp

The AC-Al composites' theoretical densities were calculated with the help of this rule of mixture:

$$\rho_{t=\rho_{AL}} \times \frac{W}{W}\% + \rho_{AC} \times \frac{W}{W}\% \quad [3]$$

$$\rho_b = \frac{\rho_{AC}}{\rho_t} \times 100 \quad [4]$$

Here;

ρ_{AC} = Experimentally calculated density (gr/cm^3)

ρ_b = Relative density (%)

ρ_t = Theoretical density based on powder mixture rate (gr/cm^3).

4. Results And Discussion

Microstructure and composition

Fig.1(a-c) shows that it seems homogenous and well embedded in the Al matrix, and contains 2.0% mass of the AC sample. As with the samples produced by powder metallurgy, pore formation occurred in them. Active carbon beads are not embedded in aluminum, but aluminum beads are placed at the contact

points. It has also been observed that the practical size of the activated carbon atoms is not equal. According to the SEM images of the samples used in the production of active carbon, additional composite materials were obtained from vegetables when aluminum is used as matrix; so, it is obvious in the SEM and mapping images that 2, 4 and 6% of the masses added to the Al matrix were homogenously distributed in the matrix. No agglomeration was observed. In addition, activated carbon has homogeneous distribution in the samples, which increases the strength of the obtained composite material. When Figure 2 is examined, comparing the optical image of a pure aluminum sample with the optical images of 2, 4 and 6% by weight of added actived carbon, it was observed that the added actived carbon were homogeneously dispersed in Al, and the hardness of the composite material decreased with the added amount of activated carbon (average aluminum grain sizes; % 2 AC + Al 0.30 μm, % 4 AC +Al:0.47 μm, 6 AC % +Al:0.53 μm) and didn't undergo any agglomeration. At the same time, it is observed in the optical images that an interface layer is formed between the Al/AC in the composite. The hemogenous distribution of actived carbon samples added to the matrix in the composite material positively contributes to the materials' mechanical properties. Heterogeneous distribution found in the added materials adversely affects the composite material hardness. It is seen in the optical images that the added activated carbons are firmly held by the matrix.

The XRD results for aluminum, aluminum oxide and activated carbon are shown in Fig.3. When the graphs were analyzed, peak intensity increased in parallel with the activated carbon quantity, which is added to Al. C peaks are observed in 6% activated carbon samples, although they are small. Again, when the graph is examined, the source of the Al_2O_3 peak is seen in the samples, which slightly oxidizes the surface during the preparation of the samples. This result also supports the EDS data.

Fig.4. shows that Vickers hardness test and this test was performed to monitor the effect of 2% to 6% mass of activated carbons on the matrix of aluminum alloy. The variation in hardness values of Al matrix composites is shown in Fig.4. Pure aluminum has been observed to have less hardness. With the addition of 2% activated carbon, the hardness of the composites reached the highest value. The high stiffness of the composite materials was associated with the presence of hard particles of additive materials, which constitutes an obstacle to dislocation. Since the activated carbons are harder than aluminum, the amount of activated carbon increase by mass decreases structural hardness.

Fig.5. shows the hardness change with increase in weight percentage of activated carbon. It is obvious in the figure that the lowest hardness existed in the case of pure aluminum; however, when activated carbon was increased to 2%, its microhardness value became the highest. The observed increase in hardness value was tripled as compared to pure aluminum. It also matched the previous Vickers hardness test results. Hardness decreased when activated carbon quantity was increased. This increases the activated carbon quantity, and weakens the matrix structure due to weak van der waals interaction with aluminum, which reduces hardness; therefore, the best ratio of the activated carbon reinforcement to the aluminum matrix was found to be 2% activated carbon reinforcement. According to the elastic modulus graph shown in Figure 6, the elastic modulus values increased by 3.4 times (9.59GPa) compared to aluminum with the addition of 2% activated carbon. The elastic recovery rate was also quite low in Table 3.

Experimental and relative densities of Al matrix activated carbon with added composites are given in Table 2. Experimental densities vary between 2.28-2.44g/cm^3 and theoretical densities vary between 2.54-2.70g/cm^3. As the amount of activated carbon added to the pure aluminum increases, the theoretical densities decrease compared to the experimental densities. This decrease in density happens due to formation of pores in the Al matrix during sintering at 550°C and the absorption of air into the pores. The relative densities vary between 88.80-95.6. High strength/density ratio is preferred in several engineering products.

5. Conclusion

The composite material was obtained very successfully by using the activated carbon aluminum matrix powder metallurgical method obtained from the plant material. The activated carbons added according to SEM-EDS images are homogeneously dispersed in the aluminum matrix. According to optical photographs of the Al-AC composite material, as the amount of activated carbon added to the aluminum matrix increases, the average aluminum grain size decreases. In the XRD results, very little Al_2O_3 was formed, mainly due to the aluminum phase, which occurs due to oxidation. This phase also occurred during the production of the composite.

This increases the activated carbon quantity, and weakens the matrix structure due to weak van der waals interaction with aluminum, which reduces hardness; therefore, the best ratio of the activated carbon reinforcement to the aluminum matrix was found to be 2% activated carbon reinforcement.

Vickers Hardness and Dynamic Micro Hardness results support each other too and the sample with 2% AC added has the highest hardness value. With the addition of 2% activated carbon, elastic modulus values increased by 3.4 times (9.59GPa) compared to aluminum. Also as seen in Table 3, the elastic recovery rate is also quite low compared to the others.

Declarations

conflicts of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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Figures

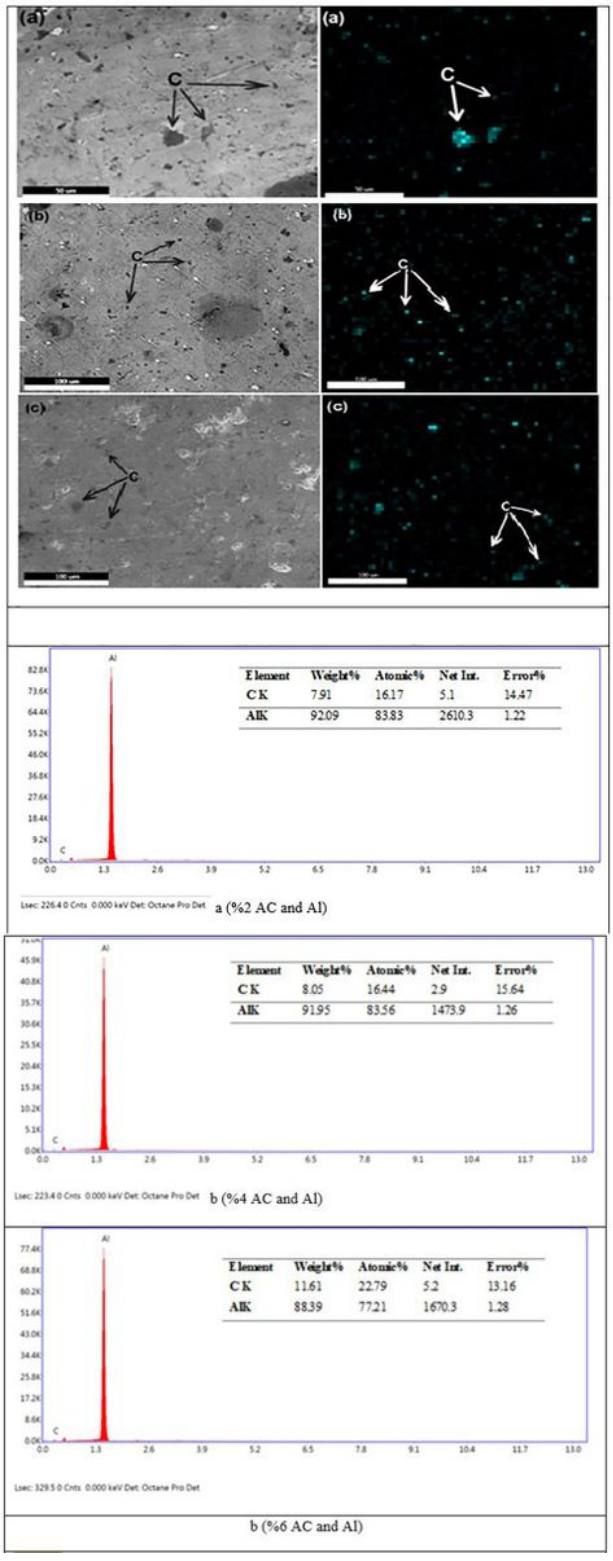

Figure 1

SEM image and Energy dispersive spectrometer measurement (EDS) from these phases are given of Al–AC composites: (a) 2% Ac, (b) 4% Ac, (c) 6% Ac

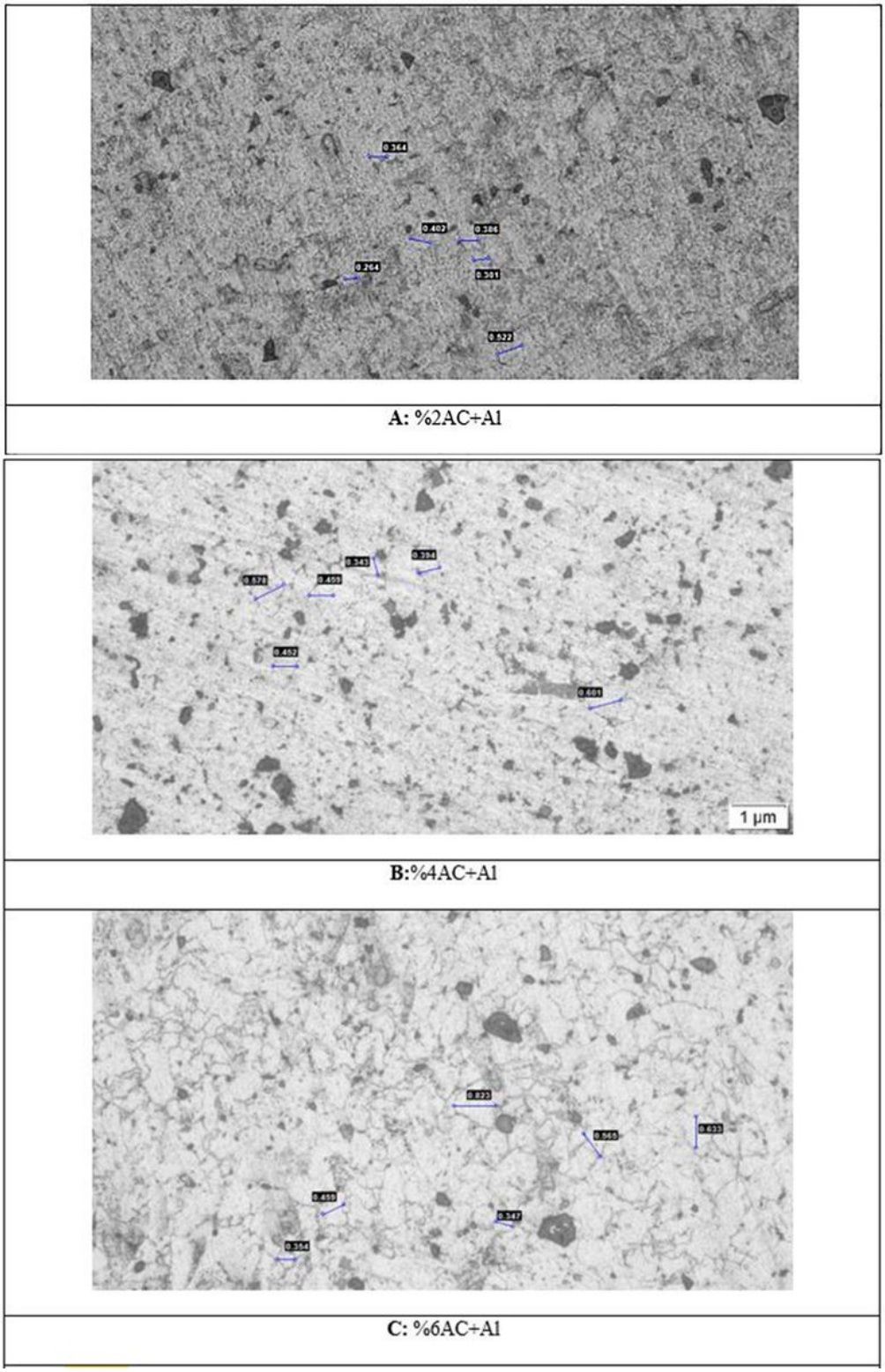

Figure 2

Optical images of composites: A: %2AC+Al, B:%4AC+Al, C: %6AC+Al

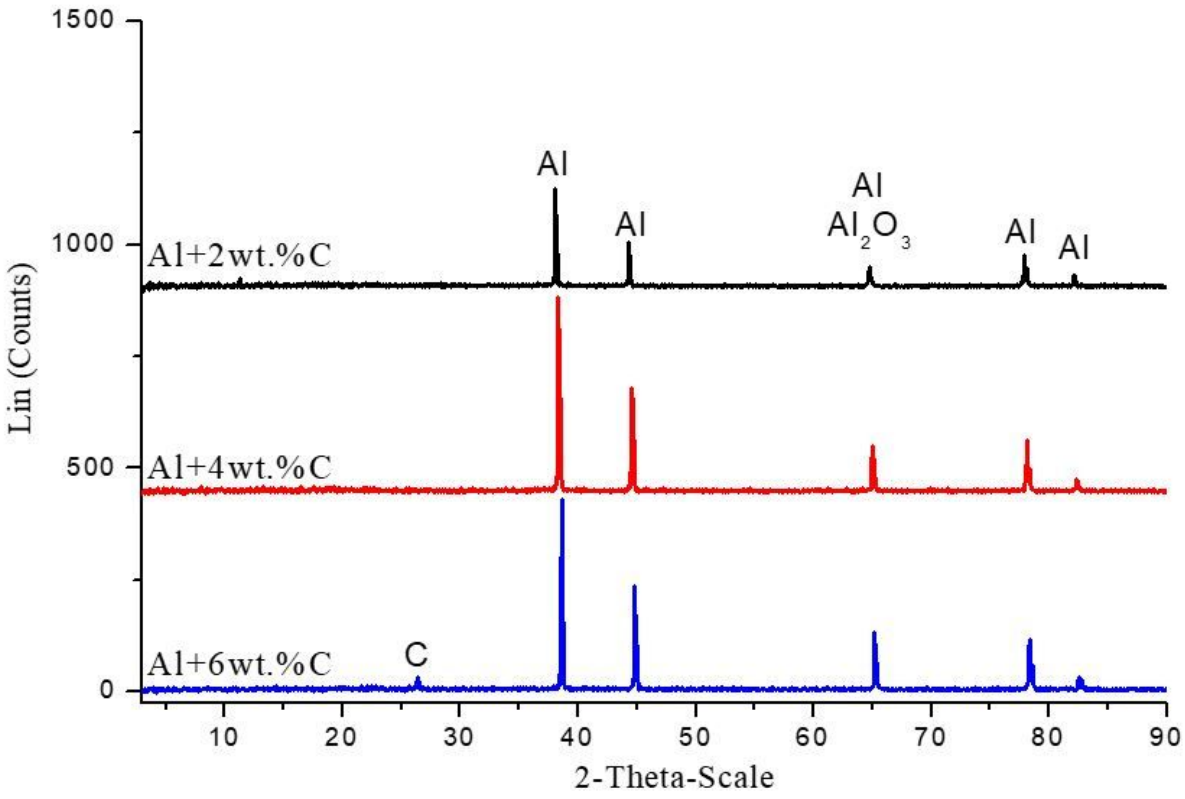

Figure 3

XRD patterns of activated carbon and composites

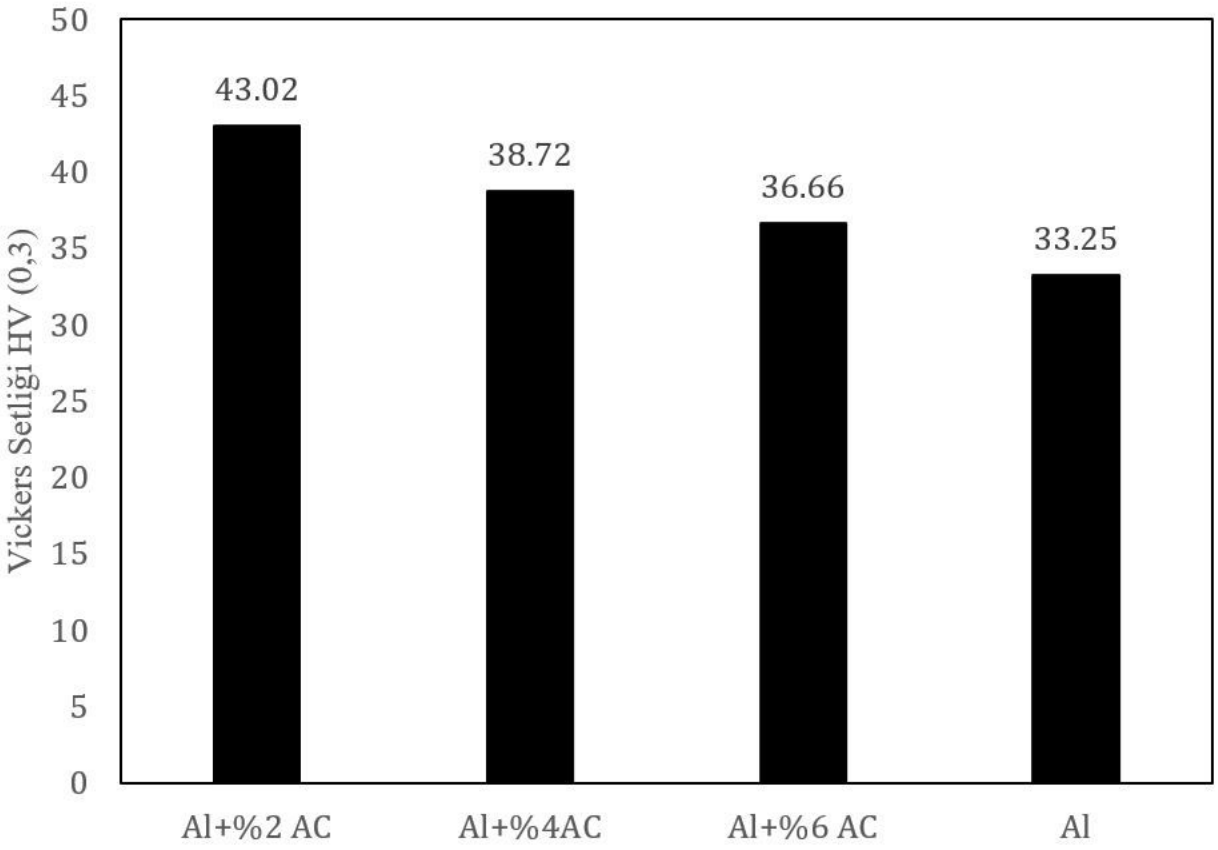

Figure 4

Hardness values obtained by adding different activated carbon quantities to pure Al

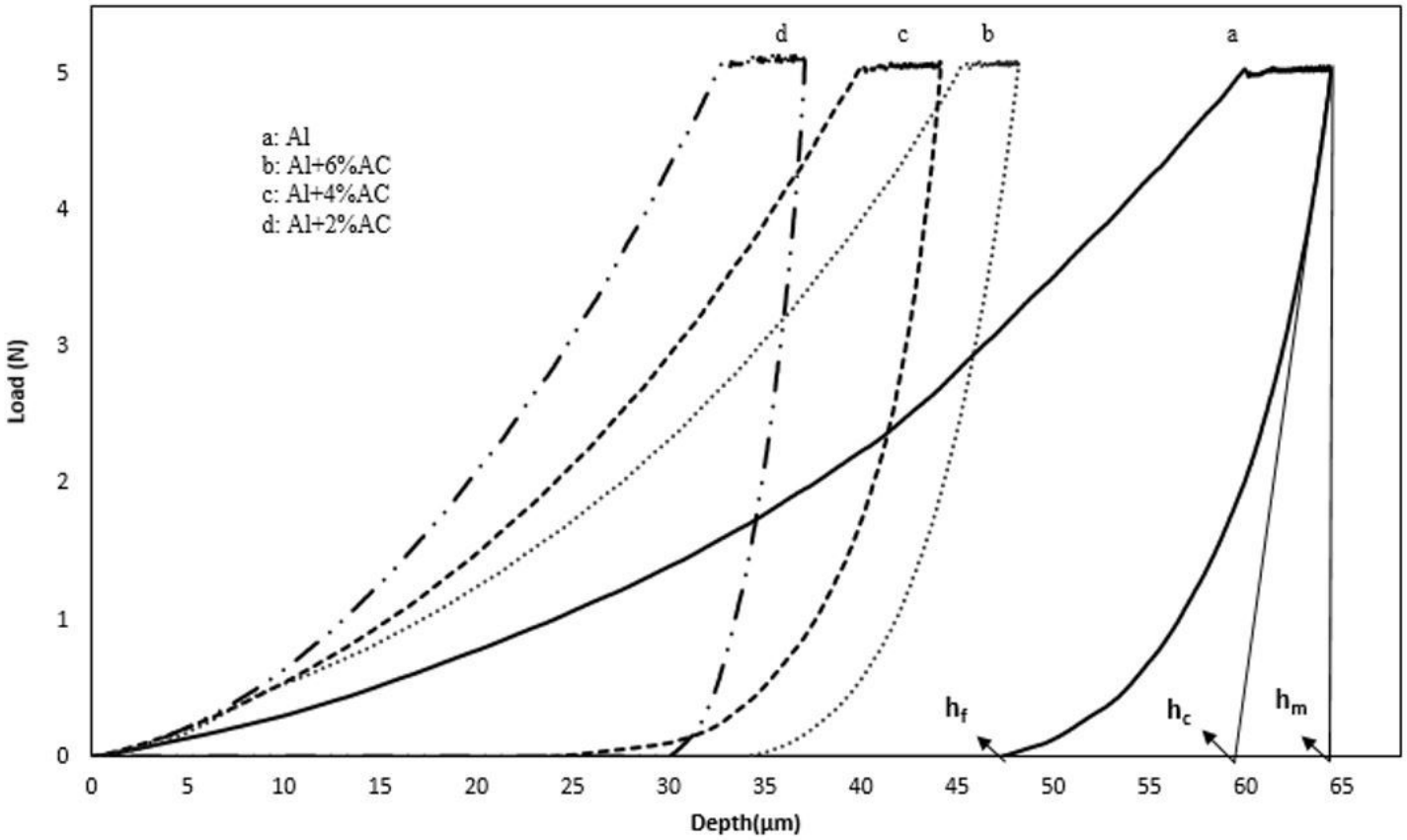

Figure 5

Graph of loading-unloading/depth of activated carbons added to pure Al and Al in different

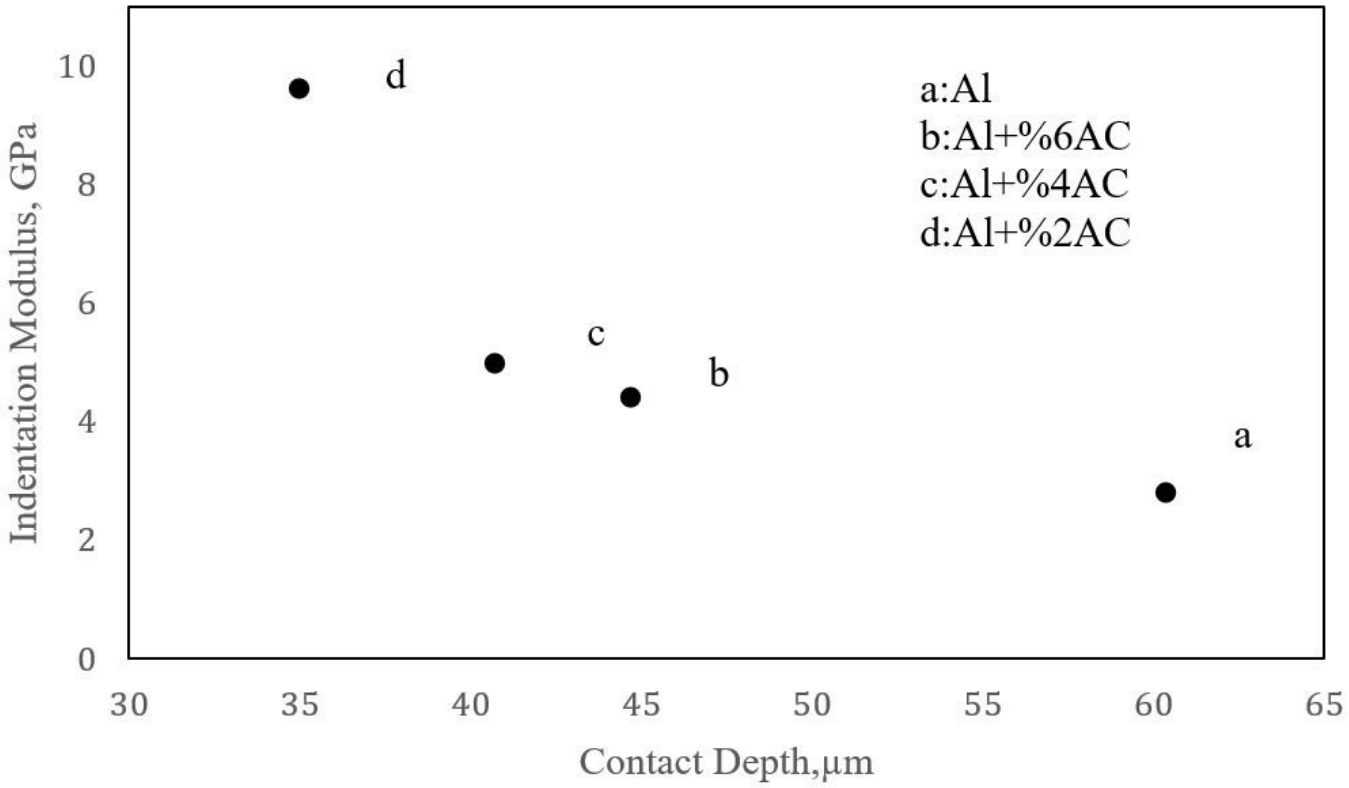

Figure 6

Elastic modulus values obtained from dynamic hardness test