


A Study to Define Critical Current Limit for Covetic Al Formation

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Abstract

This paper presents the production steps of Al covetic material, as well as a margin for the critical current in its production process along with stress-strain mechanical measurement results. As the need for energy is increasing every day, it is getting important not only its production but also its transmission in power grids. Covetic metals, one alternate to superconductors, show high electrical conductivity property for that purpose. During covetic production, a metal matrix is first melted and then mixed with Carbon Nanotubes (CNTs) before a high DC current is applied to the molten material. The role of this DC current is important in covetic material production and still under investigation. In the course of study, covetic samples have been produced for four different current values, namely 100A, 200A, 300A and 400A, applied for 10 minutes, and one sample without a DC current, all having CNT-Al mixing ratio of 1% by weight. Another sample was also produced without CNT doping for comparison purposes. Obtained results have showed that covetic material formation takes place for DC current values greater than or equal to 200A based on conductivity comparison of the samples. It is also observed that covetic materials show increased flexibility.

Keywords: Covetic, cnt, conductivity

Kovetik Al Oluşumunda Kritik Akım Sınırını Belirlemek İçin Bir Çalışma

Özet

Bu çalışma, Al kovetik malzemesinin üretim aşamalarını, bunun yanı sıra üretiminde kritik akım için bir aralık ile birlikte gerilme-gerinim mekanik ölçüm sonuçlarını sunmaktadır. Enerjiye olan ihtiyaç her geçen gün artarken, elektrik şebekelerinde sadece üretimi değil, iletimi de önem kazanmaktadır. Süperiletkenlere alternatif olan kovetik metaller bu amaçla kullanmak için yüksek elektriksel iletkenlik özelliği gösterirler. Kovetik üretim sırasında, bir metal matris önce eritilir ve ardından erimiş malzemeye yüksek bir DC akımı uygulanmadan önce Karbon Nanotüpler (KNT'ler) ile karıştırılır. Bu DC akımının rolü, kovetik malzeme üretiminde önemlidir ve halen araştırılmaktadır. Çalışmada hepsi ağırlıkça % 1 CNT-Al karışım oranına sahip, 10 dakika süre ile 100A, 200A, 300A ve 400A olmak üzere dört farklı akım değeri için ve DC akımı uygulanmayan kovetik numuneler üretildi. Başka bir numune ise karşılaştırma amacıyla KNT katkılanmaksızın üretildi. Elde edilen sonuçlar, numunelerin iletkenlik değerlerinin karşılaştırmasına dayalı olarak, 200A'ya eşit veya daha büyük DC akım değerleri için kovetik malzeme oluşumunun gerçekleştiğini gösterdi. Ayrıca kovetik malzemelerin daha fazla esneklik gösterdiği de gözlenmiştir.

Anahtar Kelimeler: Kovetik, knt, iletkenlik

1. Introduction

The necessity of energy in daily life both for individuals and countries is constantly increasing. While the current power grid in the world can carry the energy of approximately 1GW that is good to meet today's needs (Smalley, 2005), it may not be sufficient to carry the energy needed in the coming years (Alvarenga, 2010). Moreover, considering the cross-section, weight and current carrying capacity of wires such as Cu and Al, used in current transmission lines, the transmission of hundreds of GW of energy that will be needed in the future is not possible with the current grid infrastructure (Smalley, 2005; Alvarenga, 2010). There are new conductors having the potential to perform close to superconductors.

One of the materials studied in this sense is composites, called covetics. In general, composite materials are structures that are formed by combining more than one material at macro level in order to correct each other's weaknesses and combine their superior properties. It has been reported in the literature that covetic materials, which are defined as nanostructured metal composites of nano-sized materials like Carbon Nanotubes (CNT) and metals, have superior properties (Bakshi et al., 2010; Ga and Xavier, 2014). Studies also show that the conductivity of covetic wires is better than pure metals, and its conductivity can be further increased (Knych et al., 2014). In addition, the thermal conductivity, mechanical strength, oxidation and corrosion resistance, current carrying capacity of these materials are significantly superior than pure metals such as Cu and Al, and there is an intense interest in them as they have the potential to be used efficiently in energy transmission (Behabtu et al., 2013; Bakir and

Jasiuk, 2017). In the most up-to-date technique, used to produce graphene containing composite structures between the planes of metal atoms, covetics are obtained by adding CNTs to the molten metal and applying high DC current to activate the carbon atoms (Varnell et al., 2019; Forest et al., 2012). Although the role of high current applied to the melt is not fully known, it is assumed that DC current is necessary to obtain covetics and contributes to covetic structure formation by transforming large carbon structures into activated carbon (Knych et al., 2014). Salamanca-Riba et al. (2015) suggest that covetic structures begin to form for DC current values above a threshold value, called critical current. Hence, carbon atoms re-arranged to form alternating graphene layers within metal matrix while below that threshold value covetics are not obtainable. In covetic structures, metal-to-metal, carbon-to-carbon and metal-to-carbon bonds are in the form of metallic, covalent and van der Waals, respectively (Yang et al., 2020). In a study by LANL (2011), it is shown that the production cost of nano-carbon based composite wires, called as ultra-conductive, is lower than that of non-covetic metal while enabling hundred times higher current carrying capacity. Hence, covetic materials suggest economic possibilities for energy transmission as well as other usages and deserve further research.

In this study, covetic composites were produced using different DC currents in order to examine the role of current in the production of covetic materials by using aluminum as the metal matrix and Single-Walled Carbon Nanotubes (SWCNTs) as the carbon material. By comparing the electrical resistance and mechanical Stress-Strain properties of the obtained samples, the covetic formation and improvement in the

covetic material properties was observed. A critical current range in Al-covetic material production was also determined.

2. Material and Methods

The work carried out in the study has twofold; the first is to produce the Al-covetic material, and the second is to electrically and mechanically test the obtained samples. This section explains both steps.

2.1. Production Process

Covetic wire production consists of the basic steps of melting the metal matrix, infusing CNTs into it, and then applying DC current to the molten mixture. In all conducted studies, 42 mm² Pansy AAC wire was used as metal matrix and Aldrich brand Single-Wall Carbon Nanotubes (SWCNTs) was used as carbon nanostructure. SWCNT to metal mix ratio was defined as 1% by weight. Metal material was first cleaned before any sample production, melted using an induction furnace, and then CNT structures infused. This step was followed by mechanically stirring metal and carbon mix. Finally, DC current is applied intermittently for certain periods. All metal melting, CNT doping, current application and mixing processes were performed in a crucible located inside the furnace coils. Among these, current was applied using a DC current source. One probe of which is connected to crucible and the other probe is immersed in melt as shown in Figure 1. After all that, the melted mix in the crucible was poured into molds and cooled down to obtain cylindrical covetic samples. The details are summarized below.

The aluminum material was first chopped into about 1cm long pieces and subjected to cleaning in order to remove the dirt and oxide layer on it. For this purpose, metal

pieces were first cleaned with water, acetone for 5 minutes, methanol for 5 minutes and HCl for 1 minute in an ultrasonic cleaner. Finally, they were washed in de-ionized water and dried.



Figure.1 DC current and argon gas application during Al covetic preparation

Following the cleaning step, all metal material was placed in the crucible and melted at a temperature of approximately 800°C. Then divided into five equal amounts and individually aluminum-foil wrapped SWCNT material was doped into the melt one-by-one, and melt was stirred for 2 minutes manually at a speed of approximately 50 rpm with the help of a stir bar after each doping. As the accumulation of carbon on the surface of the crucible and its burn is responsible for dross as well as impurity formation, a homogenous mixing of metal and carbon structures is an important step for efficient covetic material production. Finally, a chrome rod, used as current application probe, was dipped into the melt and proper magnitude of DC current was applied for another 2 minutes. All three steps of CNT doping, stirring and current application were repeated five times to ensure a good mixing performance as well as 10 minutes of total current application duration. During all steps beginning with metal melting, argon gas flow was applied into the crucible with the help of a nozzle in order to decrease the impurity formation that

may occur due to the existence of carbon, oxygen and high temperature in open atmosphere conditions. Finally, the melt, prepared in the amount of approximately 100g, was casted into one of cylindrical chrome molds, 20 cm in length and 6, 8, 12 and 15 mm in diameters. After de-molding and cooling at room conditions, samples were tested for covetic formation. A casting instance and sample after de-molding are shown in Figure 2 (a) and (b), respectively.

2.2. Conductivity Measurements

Since the specific resistance value of the obtained samples are about $3 \cdot 10^{-8} \Omega \cdot m$, and therefore, their corresponding resistance value is about couple micro ohm levels, it is not easy to measure electrical resistance of samples. For this reason, a measurement setup, similar to Resistivity by Four Probe Method, was used to determine the electrical conductivity properties of the produced samples. With that, while a current in the range of 5-50 A is applied to the sample, its electrical conductivity is determined by measuring the induced voltage on the sample. Before all measurements, the circular symmetry of the obtained samples is improved on a lathe to better define cross-sectional diameters of samples, needed in resistance comparison.



(a) Al casting

(b) Al sample

Figure.2 Mold sample used in covetic material production following melting, current application and stirring

3. Research Findings

In order to determine the role of applied DC current in Al-covetic production, six different samples were produced applying different DC currents, and the corresponding sample properties were evaluated. For this purpose, samples were produced by applying DC current values of 100A, 200A, 300A and 400A for 10 minutes as well as no current (0A) all having Al-CNT mix ratio of 1% by weight. In addition, another sample was produced using pure Al material (no CNT) without applying current. Following the production of samples, they were molded to cylindrical chrome molds, cold down to room temperature. Finally, their Voltage-Current (V-I) curves, as shown in Figure 3, as well as their approximate electrical resistance values in terms of the V-I curve slope are obtained.

Mechanical tests of two samples were also conducted to observe a possible change in the mechanical properties with the covetic formation. For that, pure Al sample and

covetic sample, produced with 300A DC current, were subjected to stress test in Stress-Strain mechanical measurement system, and corresponding results are shown in Figure 4.

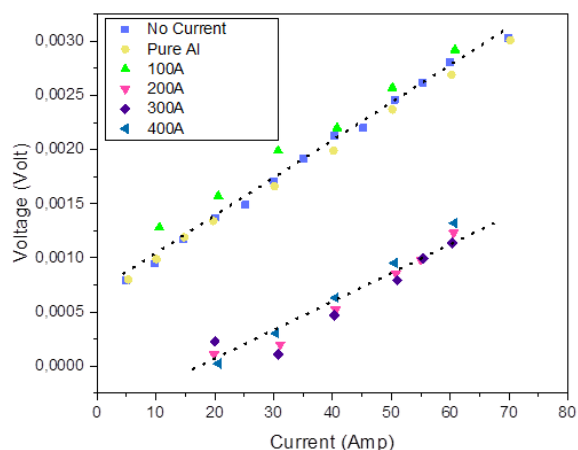


Figure.3 Voltage-Current (V-I) curves of obtained samples produced for different DC current values and pure Al

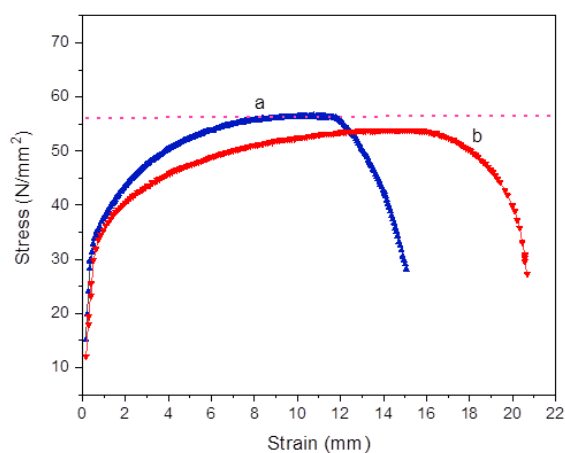


Figure.4 Stress-Strain measurements: (a) Pure-Al sample, (b) covetic sample

4. Results

From the evaluation of Figure 3, voltage measurements obtained for samples produced with smaller than or equal to 100A DC current along with pure Al sample are close to each other for the same test current values. Samples produced with DC current values

greater than or equal to 200A, are similar as well. Furthermore, the average V-I slope, the electrical resistance, of the latter group is lower than that of the former group. These assessments are considered to be the indication of the covetic formation that takes place for DC current values of 200A or higher. For this reason, 200A is considered as threshold DC current value in the formation of covetic structures for Al metal.

Based on the comparison of two curves in Figure 4, on the other hand, CNT doped and 300A DC current applied sample has an ultimate tensile strength (UTS) point for a higher strain value compared to pure Al sample. The improvement in the mechanical properties of above 200A DC current applied sample also supports the covetic formation. This result is compatible with literature regarding covetic material mechanical properties and also supports the covetic material formation result observed from Figure 3.

Improved electrical and mechanical properties of samples, obtained above a threshold current value, support use of critical current in covetic formation. Therefore, use of critical current is important and needs to be further investigated to better reveal the covetic formation mechanism.

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