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Research Article

Experimental Analysis of Electrical Conductivity, Thermal Conductivity and Hardness of Aluminium Based Alloys

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ABSTRACT: Five samples containing different weight percentages of aluminium, copper, and zinc (of which aluminium predominated over the remaining two elements) were prepared by the pressure casting method. To verify the mass percentage and uniform distribution of elements in the samples, an optical emission spectroscopy (OES) test was performed. The electrical conductivity of all samples was obtained using a sigma tester and then using the 'Weidman-Franz law' the thermal conductivity of each sample was derived from their electrical conductivity. It was found that as the mass percentage of aluminium decreases, the thermal conductivity of the samples also decreases. The hardness of all samples was also checked on a hardness tester, and it was found that as the mass percentage of Cu and Zn (with a decrease in aluminium) increases, so does the hardness of the samples.

KEYWORDS: Metal, Aluminium alloy, Electrical conductivity, Thermal conductivity, Hardness.

INTRODUCTION

Metals are extremely good conductors of electricity and heat [1]. Also, the mechanical properties of metals can change significantly if they are subjected to very fast loading [2]. But today, alloys are replacing metals because they have lower thermal conductivity but remarkable hardness, corrosion resistance, and many other properties compared to pure metals. To impart certain properties to metals or to enhance some of their existing properties, certain other metals or elements can be added to them in specific proportions to form alloys. Aluminium is a kind of metal for sustainable development due to its advantages, such as its light weight and excellent physical, thermal, and mechanical properties. However, pure aluminium is soft and therefore lacks strength, but when pure aluminium is alloyed with small amounts of copper, magnesium, silicon, manganese, or other such elements, it imparts a number of useful properties. Aluminium alloys are second only to steels for use as structural elements [3]. However, aluminium has only 60% the electrical conductivity of copper but is used in electrical transmission lines due to its light weight and cheapness. Copper alloys are among the best conductors of heat and electricity and have good corrosion resistance. Increasing the copper content of pure aluminium increases precipitation hardening through stabilization of the hardening phase [4]. The addition of copper to Al-Zn-Cu alloys affects not only their structure but also improves some of their properties, such as strength, hardness, fracture energy, creep, and fatigue strength [5]. Zinc is brittle at normal temperatures but malleable at 100°C to 150°C. It is an honest conductor of electricity.

One of the advantages of Al-based composite materials is their ability to obtain excellent performance through proper compositional control [6]. Die casting is widely used to produce alloys for which metal patterns are used [7]. Die casting can produce geometrically complex metal parts using reusable molds called dies [8]. The dies are arranged so that the pressure of the molten metal can adjust its shape according to the requirements [9]. The electrical, thermal conductivity, and mechanical properties of the ABS-graphene composite prototypes were improved. The proportion of Gr in the ABS matrix is an important parameter that affects electrical conductivity [10]. As thermal conductivity and moisture content decrease, electrical conductivity, pH, and starch content increase during potato storage [11].

Crystal structure of materials, atomic arrangement, temperature, impurities present, moisture content, heat treatment, and cold or hot treatment of the material are some of the parameters that affect thermal and electrical conductivity [12]. The electrical and thermal conductivities of exfoliated graphite compacts in the through-thickness direction (i.e., compaction direction) decrease with increasing degrees of compaction, so they are essentially linearly correlated in accordance with the Weidman-Franz law. The linearity is due to the fact that both thermal conductivity and electrical conductivity are similarly governed by the degree of preferred orientation, which in turn is governed by the degree of compaction [13]. The electrical resistivity of Mg-Al and Mg-Zn alloys increases linearly with composition. at 298 K, 348 K, 398 K, and 448 K, while the thermal conductivity of the alloys decreased exponentially with composition. In addition, the electrical resistance and thermal conductivity for Mg-Al and Mg-Zn alloys varied linearly with temperature [14]. A correlation between thermal conductivity and electrical conductivity for fine carbon fiber at higher electrical conductivities using a steady-state, briefly hot wire method was proposed [15]. The hardness of samples of eutectoid Zn-Al alloys is substantially increased by the addition of copper [16]. The addition of Al to Cu increases the hardness by 96.8%, followed by the addition of Zn by 21.6% due to solid solution hardening [17]. With increasing Cu content, tensile strength and hardness increase due to precipitation hardening [18].

MATERIALS AND EXPERIMENTAL METHODS

Material Preparation

Aluminium 6063, benecreat 18-gauge copper, and zinc ingots were used as constituent elements to make alloys. All the alloying elements were weighted on an electronic balance (having the least count of 0.1 mg) as per the following mixing ratios.

A pressure casting method was used to produce the alloys. Various equipment, such as an electric weighing machine, containers for loading various samples, crucibles, furnaces, patterns, quenching water, hand grinders, lathes, surface grinders, etc., were used to obtain the final samples. These alloying elements were selected as Al-Zn. The Cu ternary system is one of the most important alloy systems [19]. For casting Al-Cu-Zn alloys, Zn was melted first because it had the lowest melting temperature compared to Al and Cu, followed by Al and then Cu. The required amount of all elements was poured into a crucible [20], then it was placed in an oven at 1123.15 K for 75 minutes and mixed gently. The molten metal was then poured into the pattern, where it was kept in the pattern for 2 hours at room temperature to cool and solidify. It was then removed from the pattern and cooled through a quenching process. The samples were then allowed to cool again at room temperature within 24 hours. The excess material was removed from the casting by the application process. To obtain the desired shape and size of the samples from the actual casting, a machining process was carried out to remove excess materials using a common lathe. To achieve a good surface finish, a grinding process was carried out.

Table 1: Mixing ratio of alloying elements in the samples

Sr. No.	Sample Name	Weight Percentage of Alloying Elements in Samples		
		Aluminium	*Copper*	*Zinc*
1	S1	100	0	0
2	S2	90	5	5
3	S3	80	10	10
4	S4	70	20	10
5	S5	70	10	20

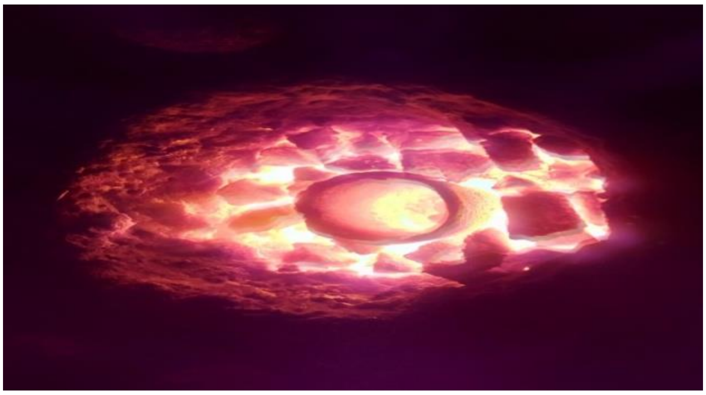

Figure 1: Melting of Aluminium, Copper and Zinc in furnace

Optical Emission Spectroscopy

The optical emission spectroscopy test was performed by the German company 'Spectro Analytical Instruments GMBH & CO KG Boschtrasse 10 d-4733' with model number LAVM10 to ensure uniform distribution and mass percentage of alloying elements in all samples.

Electrical Conductivity Tester

A Sigma "Digital Lux Meter 101" tester was used to measure the electrical conductivity of all samples. It was measured initially in % IACS, then converted in S/m later using appropriate formula.

Hardness Tester

A Rockwell Hardness Tester manufactured in the USA with serial number 6408 was used to measure the surface hardness of all samples. At least 5 indentations were made on each sample and average value of hardness were taken in consideration.

RESULT AND DISCUSSION

Optical spectroscopy tests were performed on all samples, and it was found that weight percentages of aluminium, copper, and zinc were present in all the samples nearly as they were taken during synthesis, with uniform distribution. Fig.1 shows variation in weight percentage of aluminium, copper and Zinc in all the samples. It can be clearly seen that it is very near to the desired weight percentage.

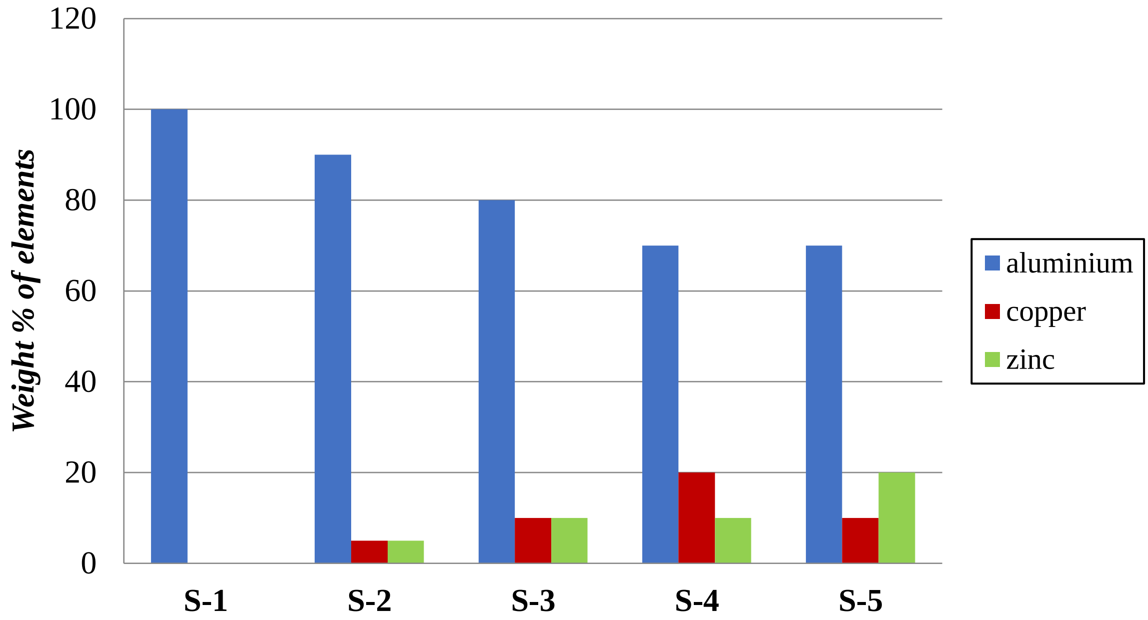

Figure 2: Weight % of Aluminium, Copper and Zinc in the samples after spectroscopy test

Electrical conductivity tests were performed on all the samples as per ASTM E1004-17 [21] at room temperature using a Sigma tester machine. The result was obtained in IACS%, which was converted to Siemens/meter using equation 1.

$$\text{Electrical Conductivity (in Siemens/meter)} = \frac{(\%\ \text{IACS} \times 10^6)}{1.7241} \qquad \ldots (1)$$

Table 2: Values of electrical conductivity of samples at room temperature (299.65 °K)

Sample Name	Electrical conductivity (in %IACS)	Electrical Conductivity (in S/m)
S1	43.23	25.07×10^6
S2	28.50	16.53×10^6
S3	25.00	14.50×10^6
S4	23.90	13.86×10^6
S5	23.00	13.34×10^6

After obtaining the electrical conductivity (in Siemens/meter), the Wiedemann-Franz Law was used to calculate thermal conductivity, which states that

$$K = L \times T \times \sigma \qquad \ldots (2)$$

Where, K is the thermal conductivity (in Watts/m.K),

T is the absolute temperature (in °K),
L is Lorenz Constant (2.45×10^{-8}), and
σ is the electrical conductivity (in Siemens/meter) [22]

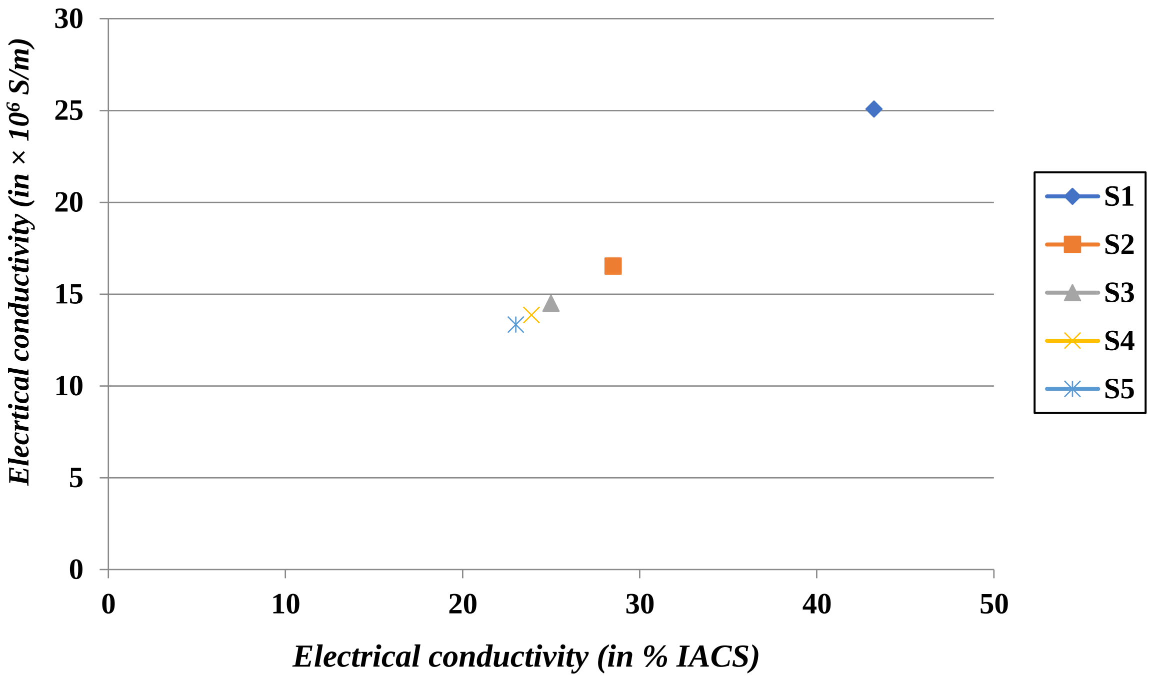

Figure 3: Electrical conductivity of all five samples

Table 3: Thermal conductivity of samples at room temperature (299.65 °K)

Sample Name	Electrical Conductivity (in S/m)	Thermal Conductivity (in W/m.k)
S1	25.07×10^6	184.0495
S2	16.53×10^6	121.3537
S3	14.50×10^6	106.4506
S4	13.86×10^6	101.7521
S5	13.34×10^6	97.9346

According to the Wiedemann-Franz law, the thermal conductivity of materials is proportional to their electrical conductivity. From the above graph, it is clear that as the percentage of aluminium decreases in the samples, its electrical conductivity also decreases, resulting in reduced thermal conductivity. However, out of aluminium, copper, and zinc, the electrical conductivity of copper is highest, zinc is lowest, and aluminium is in between them. But the percentage increment in copper is very small as compared to the percentage decrease in aluminium, which results in lower electrical conductivity and hence lower thermal conductivity. Thus, sample 1 has the highest thermal conductivity, and sample 5 has the lowest thermal conductivity. The thermal conductivity of samples is in decreasing order from sample 1 to sample 5.

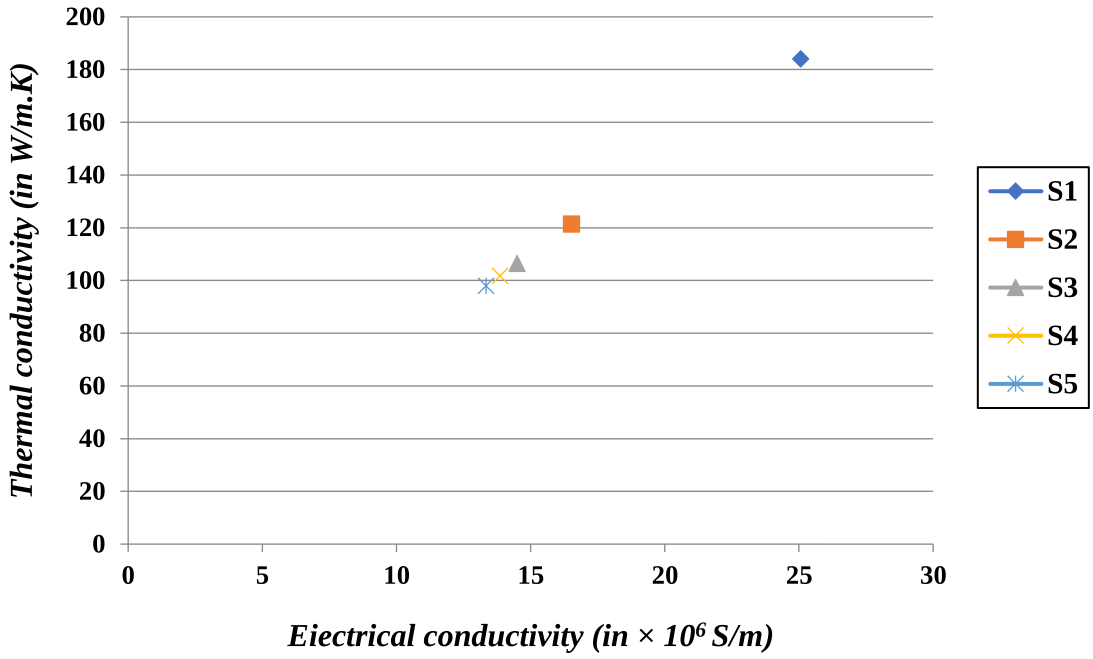

Figure 4: Variation in thermal conductivity with electrical conductivity for samples

Rockwell hardness tests were performed on all the samples by indenting the tester tip at four different places. Then the average of these four values was taken for study purposes. From figure 5, it is clear that as the weight percentage of aluminium decreases in the sample, its hardness increases because aluminium is a soft material. However, the hardness of sample 4 is greater than that of sample 5 due to the increased weight percentage of copper in sample 4. As wear loss is inversely proportional to strength and hardness, better wear resistance is expected from these alloys. Thus, sample four has the highest wear resistance.

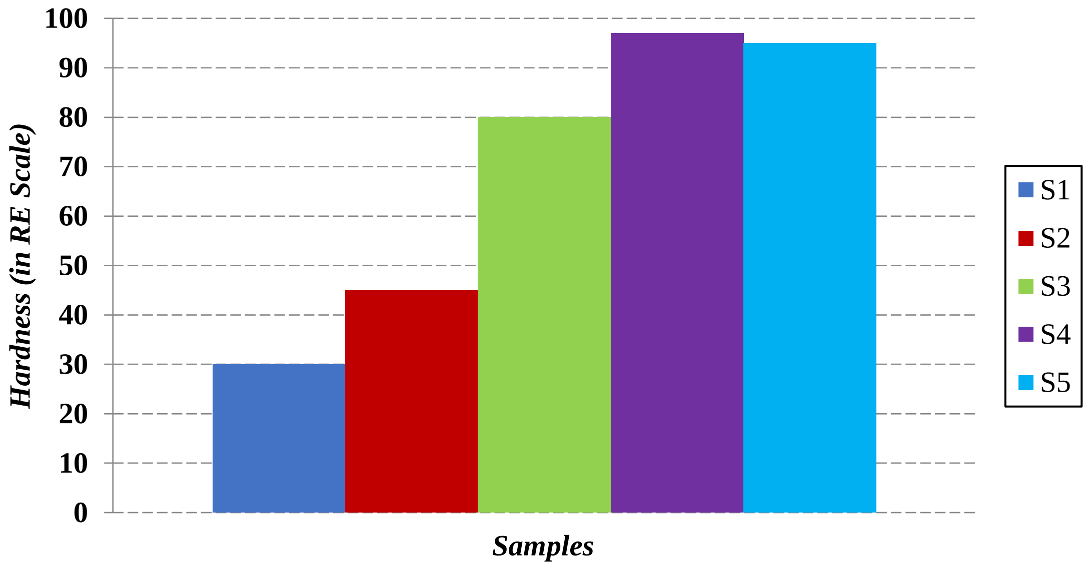

Figure 4: Surface Hardness of Samples

CONCLUSION

The experimental analysis of electrical conductivity, thermal conductivity and hardness of aluminium-based alloys plays a pivotal role in material science and engineering. These properties are crucial in determining the suitability of these alloys for various applications. Electrical conductivity measures a material's ability to conduct electric current, which is vital for applications like wiring and electrical components. Thermal conductivity, on the other hand, assesses how well a material can transfer heat, making it essential for heat exchangers and cooling systems. Hardness measures the material's resistance to deformation, indicating its durability and suitability for structural components. Through careful experimentation, researchers can fine-tune the composition and processing of aluminium-based alloys to achieve desired combinations of these properties, ultimately enhancing the performance and versatility of these materials across a wide range of industries, from aerospace to automotive and beyond. In this work, the effect of varying the copper and zinc contents in aluminium on thermal and electrical properties were investigated. It was found that the thermal conductivity of a material is firmly associated with electrical conductivity. Electrical conductivity of samples (thus thermal conductivity) decreases with decrement in aluminium content. Hardness of the sample increases with the increase in copper content results in better wear resistance.

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