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Research Article

# STUDYING THE EFFECT OF VARIATION IN VOLUME FRACTIONS OF CARBON FIBRES ON MECHANICAL AND ELECTRICAL PROPERTIES OF COPPER BASED COMPOSITES

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## ABSTRACT

Metal Matrix Composites (MMC) belong to a class of weight efficient structural materials that are becoming popular in engineering applications especially in electronics, aerospace, aircraft, packaging and various other industries. This study focuses on the effect of varying carbon fiber wt. % on the mechanical properties of the Cu-C composite. The carbon fibers were coated with copper by electroless plating in order to increase the wettability of fibers with the copper matrix. Four compositions of copper based composite were developed by varying amount of carbon fibers. The yield strength decreases with increasing fiber size while the ultimate tensile strength increases with increasing fiber size. Rockwell hardness test showed an increasing trend of hardness for increasing carbon fibers. The conductivity of Cu-C composite decreases by increasing carbon fibers content. Wear rate of Cu-C composite increases when carbon fibers content increases in the composite. SEM/EDX analysis revealed the size and distribution of fibers and indicated the fracture phenomenon.

**Keywords**: Copper based Composites, Mechanical, Electrical and Wear Properties, Microstructure

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## 1. INTRODUCTION

Metal matrix composites (MMCs) contain a reinforcing material into a metal which changes the properties of composites. The standard metalworking techniques (extrusion, forging or rolling) can be applied on discontinuous MMCs to make the properties isotropic. Polycrystalline diamond tooling conventional techniques are also used for machining the composites [1]. Korab *et al.* [2] prepared copper based hybrid composites by reinforcing tungsten and carbon fiber as reinforcing materials. The results of their research showed that the reinforcement in composites withstand high temperature thermal loading. Pavol *et al.* [3] prepared copper based composite reinforced with chromium and carbon fiber that may withstand thermal cycles between 30-1000$^{o}$C. SEM analysis revealed high structural stability against the thermal cycle and showed no signs of disintegration. Kaczmar *et al.* [4] reinforced the matrix by dispersion of particles, platelets, non-continuous (short) and continuous (long) fibers in metal matrix composite using different preparation methods. The developed composites showed better mechanical properties. Zhu *et al.* [5] used controlled three-step electrodeposition method to prepare carbon fibre-reinforced copper composite materials. The effect of processing parameters such as hot pressing temperature, pressure, duration and reinforcement content on the development of these composites were studied. The results of their research suggested that the relatively optimum production parameters are 30 wt% fibres, 700 $^{o}$C temperatures, 40 min duration and 10 MPa pressure to produce a composite with optimum properties. Xiaa *et al.* [6] prepared lead free copper and carbon fiber reinforced copper alloy composites and studied the mechanical properties and wear behaviour of composites. Wear mechanism of the leaded copper alloy was adhesive in nature and the optimum substitute for the leaded copper alloy was 12 vol. % carbon fiber/Cu–Sn–Zn composites. Yiping *et al.* [7] reinforced short carbon fibers (CFs) in copper matrix and studied friction and wear properties of the developed composites .The results indicated that with an increase in carbon fiber volume fraction improved wear resistance has been achieved. Both friction coefficient and wear mass loss was increased by increasing load and rotating speed. Dong *et al.* [8] reinforced carbon nanotubes in copper matrix and studied the friction and wear behaviour of composite. The results showed that wear rate of the composites were decreased by volume fraction of nanotubes in composite. The optimum value of carbon nanotubes were found 12–15% for both the coefficients of friction and weight loss of the nanotube/copper composite. Gre´gory *et al.* [9] reinforced copper and aluminium matrix (Cu–CF and Al–CF) composites with fully dense carbon fibers by hot pressing method. It was found that the thermal strain caused by the thermal expansion coefficient (TEC) mismatch between the matrix and the carbon fiber enabled mechanical enhancement at the matrix/carbon fiber interface and allowed conservation of the improved TECs of Cu–CF and Al–CF composites after thermal cycles. Jacek *et al.* [10] prepared the copper based composite materials reinforced with alumina particles or fibres using squeeze casting method. Offset yield strength $R_{0.2\ improved}$ by particle reinforcing, which remained almost constant in entire temperature range of 20-300°C. Reinforcing with fibres caused to increase bending strength whereas particles improved strength only at higher temperatures. Composite materials reinforced with 20% of fibres and 50-60% of particles showed less wear rate during dry sliding tests performed under pressures of 0.2 and 1.0 MPa, as compared to unreinforced copper correspondingly.

This study will focus to develop and characterize carbon fiber copper based hybrid composites using compocasting technique.

## 2. EXPERIMENTAL DETAILS

A copper melt was prepared to be used as a matrix along with short carbon fibers as reinforcement by compocasting. Four castings were prepared with different wt.% of carbon fibers and were electroless plated to improve the wettability of fibers before their use as reinforcement. Carbon fibers were cut down into a length of 1-2mm and were treated in the following solution. The electroless plating was achieved by maintaining the bath temperature 40-70$^0$C having composition as shown in Table 1.

**Table 1.** Bath specification for electroless plating of copper on fibers

| Chemicals | Quantity (g/L) |
|---|---|
| Copper Sulphate ($CuSO_4$) | 12 |
| Sodium Hydroxide (NaOH) | 22 |
| Sodium Potassium Tartarate Tetrahydrate ($KNaC_4O_6.4H_2O$) | 55 |
| Formaldehyde (CHOH) | 35 |

### 2.1. Operating conditions for casting

In order to have a sound and defect free casting, some important measures were taken which are given below:

1. Pouring Temperature= 1150°C-1200°C
2. Overall flux for every heat= 1.5 grams
3. Degasser for copper alloys is required.

### 2.2. Specifications of castings

A total of four heats were developed (four different castings), each having different composition of carbon fibers as reinforcement and were named as castings 1,2,3,4.

**Table 2.** Casting compositions

| Heating | Amount of carbon fiber (grams) | Amount of copper (grams) |
|---|---|---|
| 1 | 3.25 | 650 |
| 2 | 6.5 | 650 |
| 3 | 9.75 | 650 |
| 4 | 13 | 650 |

The casting technique involved melting of copper along with the carbon fiber in furnace above the melting temperature of copper i.e. $1080^0$C followed by pouring in the mold. The pouring was preceded by thorough stirring of the melt in order to have a proper mixing of carbon fiber in the molten copper followed by pouring. In order to have a defect free casting, vents were introduced in the mold for the purpose of escape of mold cavity gases to avoid porosity in the casting. The change in the temperature of the melt was constantly monitored by thermocouple. The carbon fibers were dispersed in the molten metal copper bath and poured in the mold in order to have sound casting. After solidification, gating system was removed and finished castings were obtained. Specimens for tensile testing were cut out from all of the four castings with different composition to carry out the tensile test on each sample. The tensile specimens were prepared according to ASTM E8/E8M - 11. The length of the specimen is 30mm having a gauge length of 25 mm. The specimens are of round shape. Specimens were analyzed by using Light optical microscope and SEM/EDX. Hardness test and tensile test have been performed to notice the mechanical behaviour. Electrical conductivity has been recorded by using two points probe method.

## 3. RESULTS AND DISCUSSION

### 3.1. Tensile strength of copper-carbon fiber composites

An increasing trend of tensile strength was found with an increase in wt. % of carbon fibers as shown in Fig 1. During the tensile test carbon fibers were pulled out from the matrix in different directions. This pulling action increased the tensile strength and caused delay in fracture mechanism. The mechanism may be noticed in Fig 4c. Fig. 2 shows a comparison of the tensile strength for all samples of copper-carbon fiber composites. All samples showed an increasing trend of tensile strength while a decrease in yield strength with increasing wt. % of carbon fibers in copper.

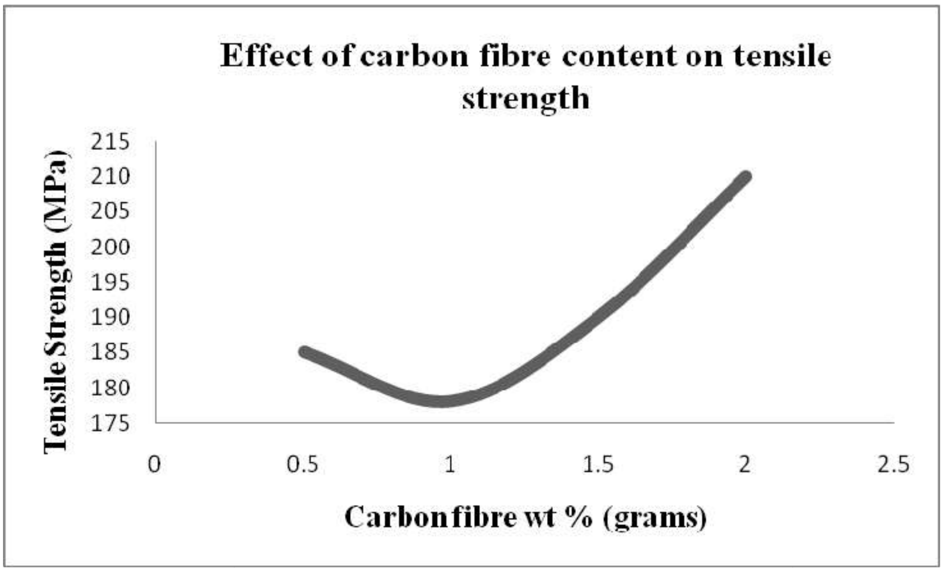



**Fig.1.** Tensile strength of copper-carbon fiber composites

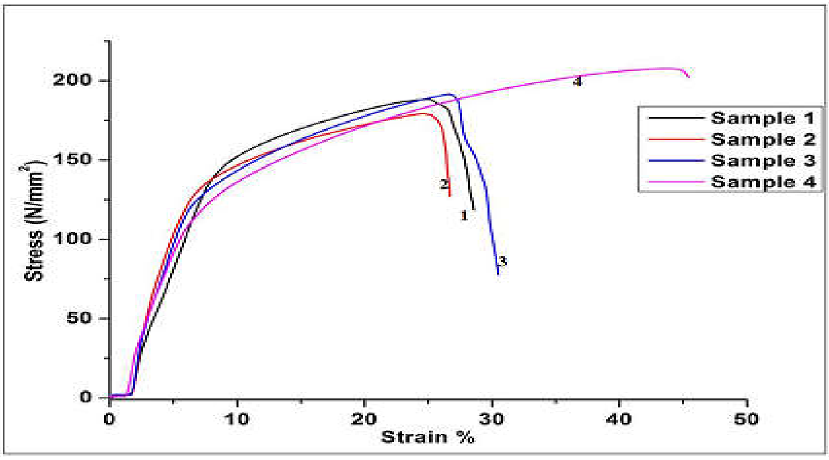



**Fig.2.** Comparisons among the stress-strain curves of copper-carbon fibre composites

### 3.2. Hardness test results of copper-carbon fiber composites

The hardness test results are displayed in Table 2 indicates that there is an increasing trend of hardness value with the increasing carbon fiber content. Starting from the sample 1 having lowest amount of carbon fiber possesses lowest hardness value and further increasing of carbon fiber in sample 2 and sample 3 have subsequently enhanced hardness values and reaching at the sample 4 which has highest amount of carbon fiber has a maximum value of hardness among all the samples. There is an increasing trend of wear resistance values with the increasing carbon fiber content. The three indents have been made on three different points in the sample in order to maintain the structural homogeneity.

**Table 3.** Hardness values of copper-carbon fibre composites

| Sample | Fiber Content (wt. %) | Readings for three indents | | | Hardness(HRF) $\frac{(1st + 2nd + 3rd)}{3}$ |
|---|---|---|---|---|---|
| | | $1^{st}$ | $2^{nd}$ | $3^{rd}$ | |
| 1 | 0.5 | 32.9 | 26.9 | 30.9 | 30.2 |
| 2 | 1 | 30.2 | 40.7 | 40.8 | 37.2 |
| 3 | 1.5 | 38.4 | 37.5 | 42 | 39.3 |
| 4 | 2 | 42.8 | 39.8 | 44.9 | 42.5 |

### 3.3. Optical microscopic analysis of copper-carbon fiber reinforced composites

The optical microscope images are shown in Fig.3 reveal the distribution of carbon fibers inside the copper matrix. Some casting defects (black spots due to oxidation) were observed in the images because the composites made through the molding technique has its effects on the structure as a whole.

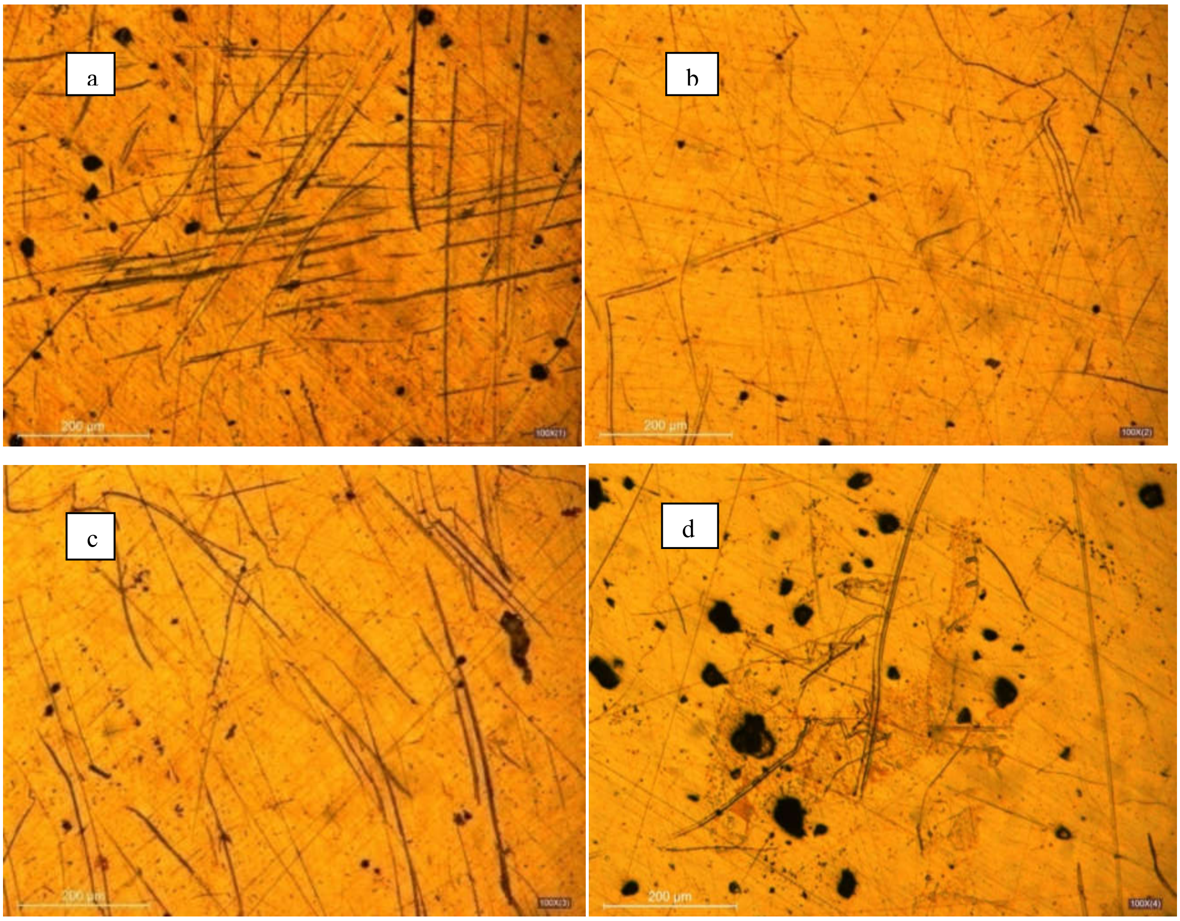



**Fig.3.** Optical microscopic images of copper-carbon fiber composites a) 0.5 wt % fibres b) 1 wt % fibres c) 1.5 wt % fibres d) 2 wt % fibres

A uniform distribution of fibres has been seen with a marginal misorientation in all of the four compositions. This type of phenomenon may lead to improved mechanical properties.

### 3.4. SEM/EDX analysis

The SEM analysis of the composite possessing different characteristics are shown in Fig.4.

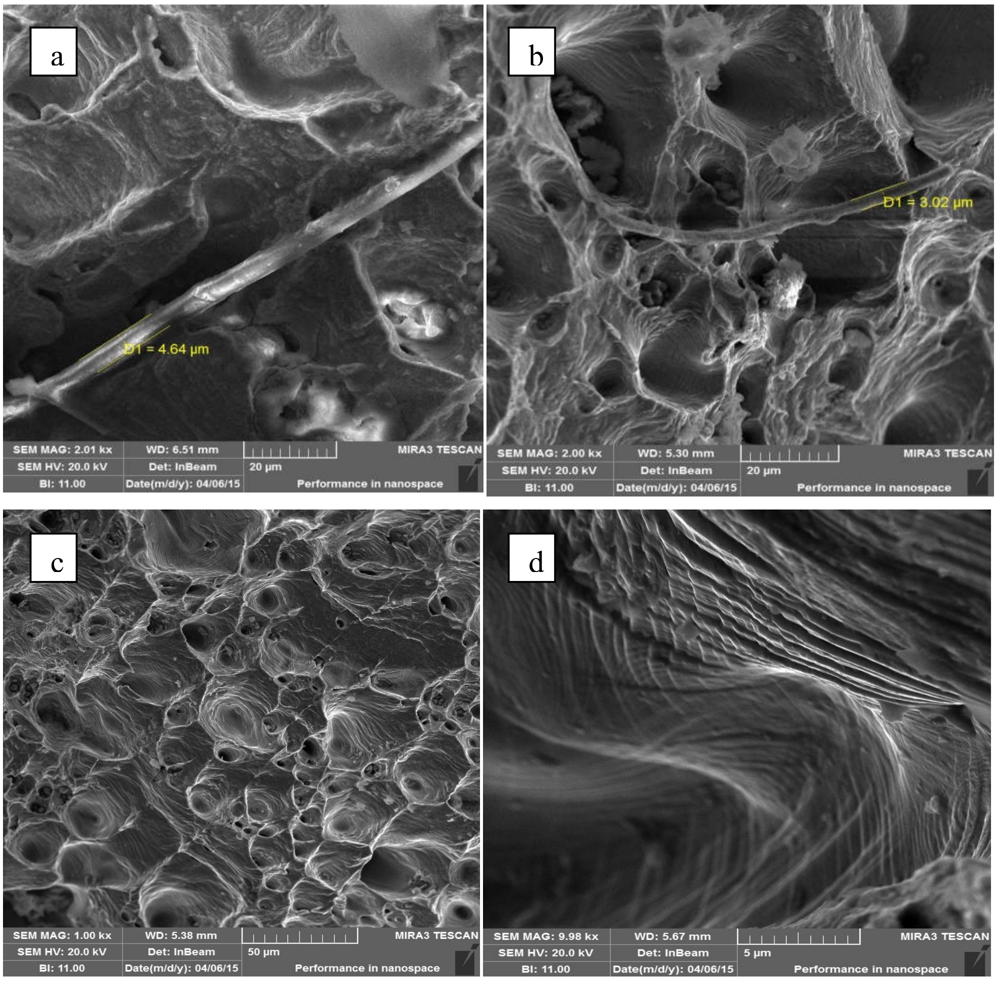
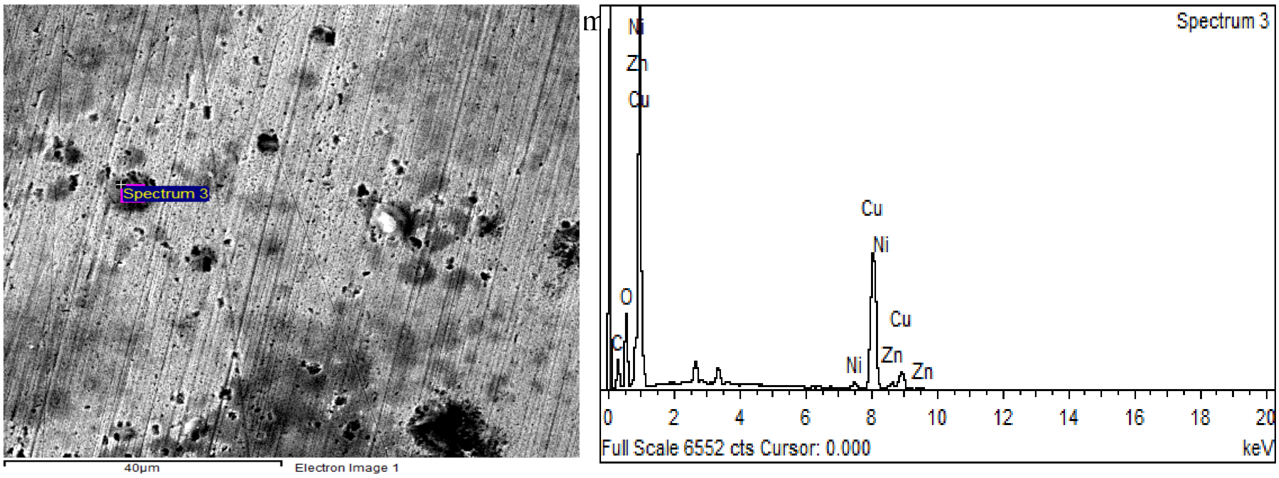



**Fig.4.** SEM microstructures of copper carbon composite a) Straight alignment of carbon fibre b) Curl alignment inside the matrix c) Fibre pull out during tension d) Beach marks revealing ductile fracture.

Fig. 4 (a) shows an aligned carbon fibre inside the copper matrix with a fibre diameter of 4.64 µm while fig. 4(b) revealed a big curl fibre with small curl fibres inserted in the copper matrix. The diameter of the fibre in this case is 3.02 µm. The curling effect has reduced the diameter of the carbon fibre. Fig. 4(c) shows a fibre pull out phenomenon during tension. The microstructure further confirms the formation of a good composite as the matrix transfer the stress to the reinforcement during tension. Fig. 4(d) shows beach marks revealing ductile fracture of the composite. The composite possesses improved strength in tension and resistance against

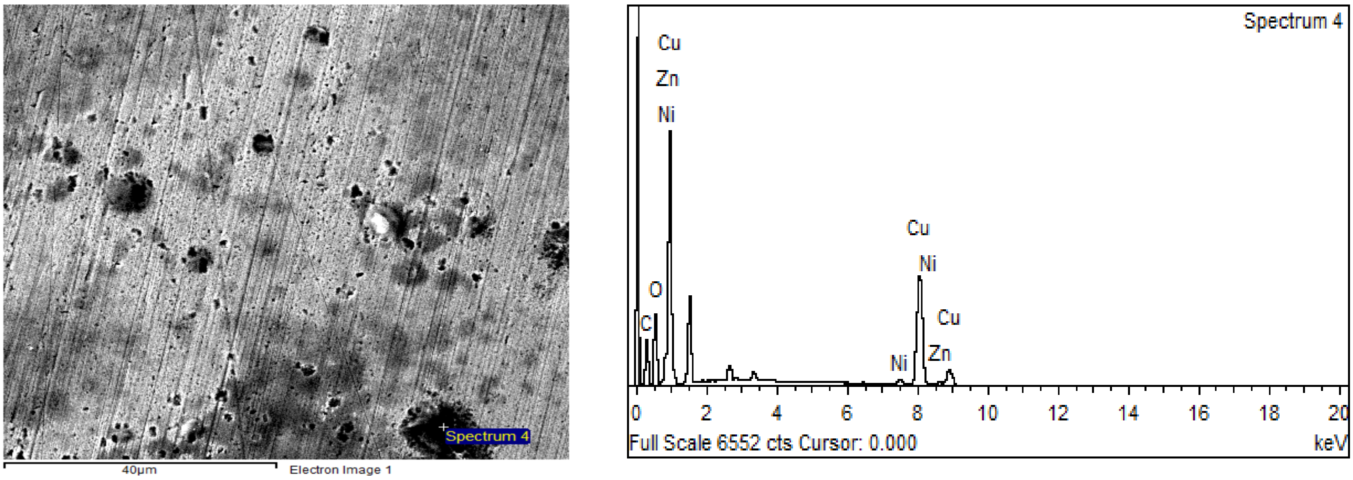



a) b)

**F ig.5.** EDX analysis of copper-carbon fibre composite a) Microstructure b) Spectrum

**Table 4.** Chemical composition of metal matrix composite (EDX)

| Element | Weight% | Atomic% |
|---|---|---|
| C K | 17.05 | 41.45 |
| O K | 14.94 | 27.26 |
| Ni K | 1.77 | 0.88 |
| Cu K | 63.41 | 29.14 |
| Zn K | 2.83 | 1.26 |
| Total | 100.00 | - |




a) b)

**Fig.6.** EDX analysis of copper-carbon fibre composite a) Microstructure b) Spectrum

**Table 5.** Composition of metal matrix composite (EDX)

| Element | Weight% | Atomic% |
|---|---|---|
| C K | 24.93 | 51.50 |
| O K | 16.48 | 25.57 |
| Ni K | 1.76 | 0.75 |
| Cu K | 55.62 | 21.72 |
| Zn K | 1.21 | 0.46 |
| Totals | 100.00 | - |

Fig. 5 & 6 shows an EDX analyses with elemental compositions are inserted in tables 4 and 5 respectively. Spectrum 3 and spectrum 4 have been taken from inclusions present in the composite. The analysis shows the presence of oxygen with a minute presence of nickel and zinc. The inclusions are porous in nature and these are typical casting defects. The analysis shows that degassing has not been effectively done and this may retard the properties of the composite. The presence of nickel and zinc might be due to non pure copper.

### 3.5. Electrical conductivity

The electrical conductivity of four samples with different fiber compositions have been carried out by two probe test method.

The conductivity of samples decreases by an increase of carbon fiber content; first sample having highest electrical conductivity due to low carbon fiber (0.5 wt. %) content in it [12]. Last one having lower conductivity due to higher carbon content (2 wt. %) and is shown in Fig.7. There are less conductive paths for electrons due to presence of carbon and they cannot easily jump from one position to the other.

The electrical conductivity of four samples depicts the following order:

Sample 1 > Sample 2 > Sample 3 > Sample 4

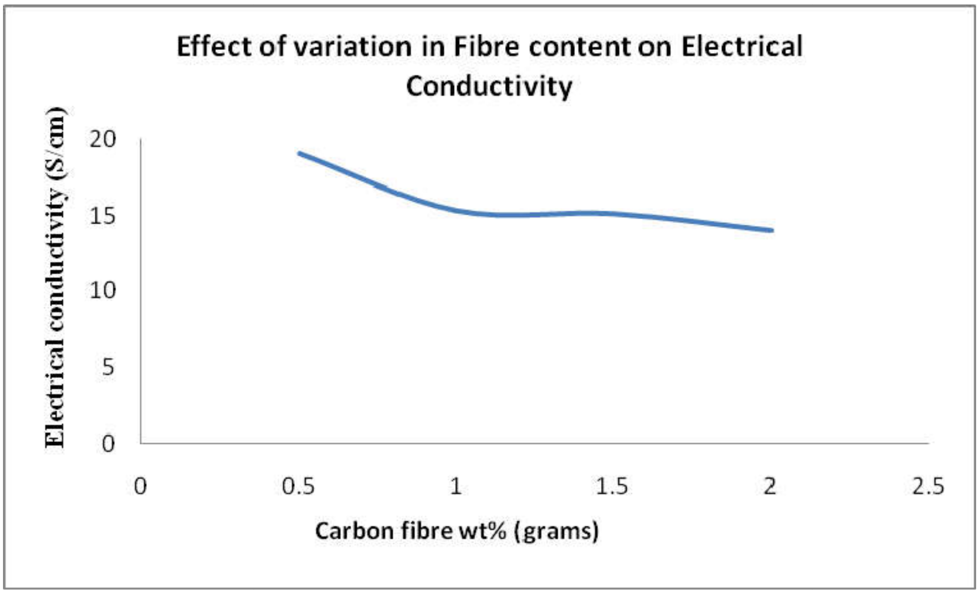



**Fig. 7.** Copper-carbon composite electrical conductivity graph

## 4. CONCLUSIONS

The tensile strength generally increases with the increasing carbon fiber content however the yield strength varies inversely with the fiber content in the composite. The hardness values of the copper-carbon fibers were found increased from 30.2 to 42.5 HRF. The obtained microscopic images revealed certain defects associated with the casting mentioning some improvement in production route. The increasing trend of mechanical properties is due to wettability of fibers with copper matrix because the surface of carbon fibers was electroless coated.

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