Preparing a Composite Material Wire Made of Copper and Graphene Nanomaterial

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Abstract— Nanotechnology is an emerging technology that is a new future of life. Various materials have their unique property and a wide range of applications in different fields including engineering as well as medical. In our developing world, we are facing problems such as the emission of CO2 and many hazardous gases due to petrol vehicles. Thus, replacing these conventional petrol vehicles with electric vehicles (EV) helps to reduce this hazardous emission. But people are not approaching the use of EVs due to some disadvantages, like slow battery charging, limited charging stations. Graphene is the lightest and thinnest material that possess solid properties such as high mechanical strength, high corrosion resistance, high electrical conductivity, etc. Thus, it has its wide range of applications in the field of biomedical, electrical, construction, etc. These problems may be solved by replacing the inner cable material of wire on the EV charging cable. The research work develops a composite material by ball milling and Hot Press Sintering (HPS) followed by drawing it into a ductile wire which helps the advancement in the field of Electric Vehicles.

Keywords—composite material; copper; electric vehicle; graphene; nanomaterial

I. INTRODUCTION

Nanomaterials can be defined as materials possessing dimension measuring 1-100nm. The definition proposed by European Commission states that the particle size of at least half of the particles in the bulk must measure upto 100nm or less. Nanomaterials can occur naturally, as the by-products of combustion reactions, or can be produced in labs through engineering to achieve their goal they are made for. Nanomaterials can have different physical and chemical properties when its processed to form part. The properties of nanomaterials, particularly their size, offer various advantages compared to the bulk-form of the materials, and their versatility in terms of the ability to tailor them for specific requirements accentuates their usefulness. Nanomaterials are also set to introduce several advantages in the electronics and computing industry. Their use will permit an increase in the accuracy of the construction of electronic circuits on an atomic level, assisting in the development of numerous electronic products [1].

In today's world, we see that scarcity of fuel is near, and to eliminate this problem engineers started to search for renewable sources of energy. As the traditional method of producing electricity is from burning coal and as coal is a natural resource it may perish to avoid this, we started generating electricity from wind and solar energy. Also, to avoid perishing of crude oil electric cars were manufactured but they were not up to customer's demand as it takes several hours to fully charged. This problem can be solved by replacing the core wire material of the EV charging cable with graphene composite as it enhances the electrical properties of conducting material. By this charging tome can be reduced and the barrier between the choice of EV can be removed.

II. LITERATURE REVIEW

In 2019, Salvo *et al.* [2] demonstrated the experiment that the graphene loading into the Cu matrix clearly influenced the mechanical and electrical conductivity by varying the sintering temperature. After testing, the graphene loaded Copper composite prepared by sintering at 600°C exhibits a minimal change in the mechanical property with a remarkable increase in the electrical conductivity when compared to the pure Cu sample. By adding 1 wt.% of GNS to the copper, the electrical conductivity was improved around 22% by comparing with the pure Cu consolidated at 600 °C. We achieved increased conductivity values of around 22% even with the lower temperature and higher applied load in the consolidation (600°C, 30 MPa, 30 min).

In 2020, Tran *et al.* [3] showed Carbon fibre(CF)/ Gold(Au)/ Copper(Cu) composite wires were successfully fabricated by sputtering Au and electrodepositing Cu on PAN-based CFs. Due to the increase of Cu layer thickness with increase in deposition time, the electrical properties of the CF/Au/Cu composite wire raised remarkably to reach metallic performance while its mechanical strength experienced a remarkable drop. Since the composite wires had CF volume fraction higher than 20%, they were lightweight (up to 70% lower than Cu mass density) and possessed the combined properties of high strength (~4 - 10 times higher than that of the pure copper) and effective electrical conductivity (up to 75% of that for pure copper). This work illustrate that CF/Au/Cu composite wire have great potential to be the next-generation electrical wires for the future demand.

In 2019, Yang *et al.* [4] successfully prepared the Silver (Ag)/graphene (G) composite wire based on the HQG, via high-energy ball milling and subsequent SPS treatment. Due to high crystallinity and integrated structure of the high quality graphene (HQG), the Ag/HQG composite exhibits an enhancement of conductivity and mechanical properties. The composite has an increase in the electrical conductivity of 11% and the microhardness of 48%, when compared with pure Ag.

In 2019, Wang *et al.* [5] used Copper powder and graphene powder and sintered to prepare three G/Cu composites with graphene contents of 0.5 wt.%, 1 wt.% and 1.5 wt.%. The influence of graphene contents on the microstructure and properties of the G/Cu 6 composites was investigated. In summary, the addition of 0.5 wt.% graphene can effectively improve the hardness, thermal conductivity, electrical conductivity, and corrosion resistance of the G/Cu composite.

In 2010, Fan *et al.* [6] fabricated fully dense graphene nanosheets (GNS)/Al2O3 composites from ball milled expanded graphite and Al2O3 by spark plasma sintering (SPS). The conductivity achieves 5.709×107S/m when composite has 15 vol.% GNS. The as-prepared composit.es behaved as semimetal as indicated by the temperature dependence of electrical conductivity in a temperature range from 2 to 300 K.

In 2019, Guo *et al.* [7] successfully prepared Mo2C and GNPs reinforced Cu matrix composites by impregnation reduction, in-situ reaction and subsequent forming processes. A new distribution form of hybrid reinforcing phases with uniform distribution of Mo2C at/near the interface between the graphene nanoparticles(GNPs) and Cu matrix was obtained. As a result, the 0.11 vol% Mo2C at 1.6 vol% GNPs/Cu composites had good mechanical properties. The Yield Strength of the composites reached 303 MPa, which were 72% and 23% higher than that of pure Cu and the 1.6 vol% GNPs/Cu composites, respectively. The electrical conductivity of the composites reinforced with Mo2C and GNPs is above 90% IACS because the interface improvement effect of Mo2C is dominant.

In 2020, Dhar *et al.* [8] successfully prepared Si-graphene (0.5– 1.5 wt.%) composites in his experiment by dry planetary ball milling process without addition of hazardous chemicals. Samples were ball milled by using a dry planetary ball 7 milling for 6 hrs. The graphene is found to be present in the Si-graphene (1- 1.5wt.%) composites in bi-layer form. While microstructure of silicon (Si)-graphene (0.5wt.%) composite shows random distribution of graphene, Si-graphene (1wt.%) composite shows uniformly distribution of graphene on matrix of Si. When graphene (0.5–1.5 wt.%) is added, it is observed that the specific surface area is improved significantly from 87 to 304 m2 g -1 . Si-graphene (1 wt.%) composite was found to exhibit 11% more electrical conductivity than pure Si. This experiment opens new scope for using Si with improving electrical property at elevated temperature under critical load because of presence of graphene in composite.

In 2017, Chyada *et al.* [9] prepared the graphene paper (GP), which is obtained by pyrolysis method of asphalt and ethanol mixing in the percentage of (70%) and (30%) respectively. Graphene reinforced aluminium matrix composites have been applied as reinforcing phase in molten pure aluminium (99.5%). Investigation of effects of artificial aging and cold rolling on the conductive and tensile properties of (Al-0.5% graphene) alloy was done. The aging treatment after cold rolling can improve both the electrical conductivity and tensile strength. The best electrical conductivity (36.8 MS/m) and tensile strength (180 MPa) of wire rod were obtained in alloy after the 90% cold rolling+aging at 200°C for 1hr. Adding (0.5% graphene), the improvement of electrical conductivity and tensile strength of alloy comparing with alloy is 8.9% and 168.6% respectively. The results of this study, concludes that the graphene is a essential material to improve the electrical conductivity of electric wire.

In 2015, Yun *et al.* [10] successfully prepared GNS/aluminium nitrides (AlN) composites via a hot-pressing process. The experimental outcomes showed that GNSs have symbolic effects on the microstructure, mechanical, electrical, and thermal properties of the composites. The grain size of AlN obviously decreased as the GNSs content escalated, which would produce a fine-grain-size effect with little addition of GNSs. The fracture and flexural strength of the composites containing 1.49 vol% GNSs were obviously increased, respectively, compared to monolithic AlN. the compositional dependence of the electrical conductivity displayed a percolation-type behaviour, with a percolation GNS volume threshold of 8 2.5070.4 vol%. GNSs are distributed along the grain boundaries, which would cause photon scattering. With the addition of more GNSs, the thermal conductivity of the composites decreased.

In 2017, Chen *et al.* [11] prepared highly dense GNSs/MgO composites with enhanced electrical conductivity, dielectric property and superior microwave absorbing property by hot-pressing sintering. The homogeneously distributed GNSs significantly inhibited the grain growth of MgO. The electrical conductivity of the composites showed a typical percolation-type behaviour with a percolation threshold at GNSs content of 3.34 vol%. The complex permittivity and dielectric loss of 3 vol% GNSs/MgO composite exhibited a notable variation compared to low GNSs content composites, which is ascribed to the near-percolation threshold of GNSs content. The microwave absorption of the GNSs/MgO composites can be regulated by controlling the GNSs content, i.e., electromagnetic parameters.

In 2020, Lee *et al.* [12] done the synthesis of monolayer, bi-layer, and multilayer graphene on copper (Cu) wire samples and their performances for copper wire protection were characterized. Optical images show significant oxidation of unprotected Cu wire at 200 °C, while multilayer graphene provides anti-oxidation protection up to 350 °C for at least 30 minutes. Similar as the anti-oxidation performance, multilayer graphene significantly impedes the dissolution of Cu wire in 1M ammonium persulphate (APS) solution. The etching time of copper wire with multilayer-graphene protection was doubled by comparing to pure Cu wire. Besides, multilayer graphene remarkably reduced the contact resistance between twisted-pair copper wires at both room and elevated temperatures.

In 2015, Dada *et al.* [13] For lead acid battery cathode, Interconnected graphene/PbO composites appearing sand-wish was developed. Facile processing technique which is solution base, enabled the interaction between graphene oxide nano-sheets and PbO submicron particles under mechanical stirring producing sandwich like structures containing graphene nano-sheets. The affection and interaction between graphene oxide and PbO in solution were distinct by change in graphene surface chemistry. Electrodes appeared porous and interconnected, and recording approx. 15% increase in discharge performance. By going throughout this article, we got that 16 Interconnected graphene/PbO composites had been developed for positive active material of lead acid battery. Graphene sheets co-existed with $PbO2$, and appeared as submerged interconnected plates. Changes in the surface functionalities and carbon structure of the graphene indicated bonding and interaction with PbO. There was about 15% increase in performance on discharge.

In year 2016, Chen *et al.* [14] done the work for synthesis of solution process, based on graphene/Ag NPs composite ink is presented. Very first, different weight ratio (wt.%) of graphene with respect to Ag-NPs was taken which was followed by ultrasonic process for dispersion. The effect of the wt.% of graphene and ultrasonic process time towards well dispersion ink are investigated. Then, hot-press sintering process was applied to achieve the final linked structure on the paper surface. We can achieve fairly low electrical resistivity under low sintering temperature (120°C). The effects of different wt.% of graphene and Ag NPs as well as ultrasonic pre-process time for the electrical resistivity of sintered Ag tracks were investigated. The 17 proposed Graphene/Ag Nanoparticles composite ink preparation and sintering method is promising for potential applications in flexible electronics. By this research we got that in this paper, the effect of sonication process time and wt.% between Ag NPs and graphene for the electrical property of sintered composite inks is investigated. It is found that the electrical resistivity of sintered tracks decreases as the increase of sonication process time. Additionally, the larger wt.% of Ag NPs obtained better electrical property. Nevertheless, the effect of sintering time, pressure and temperature to the electrical property of sintered sample require to further investigate. Moreover, the optimal wt.% between Ag NPs and graphene needs to explore as well in the future work.

In yar 2014, Kara *et al.* [15] prepared a report for an investigation on the possibility of using graphene nano-ribbon (GNR) as a conductive material in MMIC applications in the range of 2-20 GHz. GNRs main advantage to the applications of MMIC transmission lines is that the impedance of line can be controlled by their dimensions. The structural characteristics of graphene films grown on Ni film deposited on Si/SiO2 wafers after nickel removal were analysed by optical, FSEM and Raman spectroscopy. Graphene co-planar waveguide (G-CPW) transmission lines of various dimensions were then constructed on silicon wafers, as they are used in the integration of passive and active components in microwave monolithic integrated circuits. And by going through this We have successfully fabricated grapheme co-planar waveguide transmission lines in this work using processing steps that are compatible with semiconductor processing. Optical, FESEM and Raman spectroscopy results indicated graphene films of high quality. We have also demonstrated the use of a new technique in calibrating the probe measurements which led to improved characterization of graphene nano-ribbons at microwave frequencies. Subsequent comparison with simulation suggested graphene conductivity of about 9000 S/m in the microwave region, in good agreement with other researchers. The losses of the transmission lines were mostly due to the substrate, which take up most of the structure volume, and thus contribute the most of signal losses in high frequency integrated circuit structures. This is also due to the fact that, in contrast to conventional conductors, skin effect is almost negligible in graphene, as such most of the losses here is due to the substrate. The use of graphene nano-ribbon as interconnects for passive and 18 active elements thus could improve MMIC performance since the skin effect has been minimized, and this makes graphene a good candidate for microwave conductors in the future.

In year 2015, Phokaratkul *et al.* [16] presents a novel supercapacitor (SC) material based on 3D graphene foam-polyaniline (Pani)-Carbon nanotubes (CNTs) composite for supercapacitor applications. Graphene foam was produced by chemical vapor deposition (CVD) on Ni foam using acetylene carbon source and hydrogen gas carrier at 700°C for 3 min. Further, the foam was etched in 3M HCl for an hour to take out most of Ni support. Multi-wall CNTs powder were then dispersed in 1M HCl and addition of 0.2 M aniline monomer was done, then it was stirred and filtered to eliminate non-dispersed CNTs. Electro-polymerization in the CNTs-aniline monomer solution was then performed at working electrode potential of 0.55V. SEM and Raman characterization confirmed the incorporation of CNTs in Pani/graphene foam network with a number of nanowire features appeared on graphene foam surface and dominant D and G carbon's peaks. CV results showed that PANI's redox peaks were broadened due to the presence of CNTs, indicating amplification in pseudo capacitance. From GCD readings, it is disclosed that CNTs-Pani-graphene foam displays a high specific capacitance of 920 Fg-1 at a specific current of 0.8 Ag-1, which is more than twice higher than that of Pani-graphene foam. Through this, a novel supercapacitor (SC) material based on 3D graphene foam polyaniline (Pani)-Carbon nanotubes (CNTs) composite has successfully been developed for supercapacitor applications. Characterizations by SEM and Raman spectroscopy confirmed the incorporation of CNTs in Pani/graphene foam network. CNTs-Pani-graphene foam exhibits a high specific capacitance of 920 Fg-1 at a specific current of 0.8 Ag-1, which is more than two times as large as that Pani/graphene foam. Therefore, graphene foam-PaniCNTs composite prepared by electro polymerization is highly promising for advanced SC applications.

In year 2021, Sharma *et al.* [17] used modified hummers' method to synthesis the graphene oxide (GO) and over the concern of eco-friendly reduction method voltage application reduction process was used. Graphene oxide was reduced by dipping of Cu electrodes in the GO solution with biasing of 10V for 2hr. The result of XRD peak for GO at 10.4° and rGO at 25.9° confirm the desired material formation. The Raman spectroscopy determines the GO and rGO G-peak at 1597 cm-1, 1608 cm-1 and D peak at 1353 cm-1, 1347 cm-1 respectively. The shifting in the Raman peaks may arises due to removal of functional groups and impurity formation. The intensity ratio (ID/IG) increased after reduction from 0.89 to 0.96 indicated the increasing in disorderliness after reduction of graphene oxide. The absorbance peak is changed after reduction from 230 nm to 270 nm. The transmittance of graphene oxide is reduced from 85% to 75% after reduction. The bandgap value is also decreased from 3.84 eV to 2.87 eV for graphene oxide after reduction. The bandgap value is also decreased from 3.84 eV to 2.87 eV for graphene oxide after reduction. The measurement of resistance of graphene oxide (GO) and reduced graphene oxide (rGO) were taken from desktop bench multimeter that gives the value 2MΩ and 1.5kΩ, respectively.

In year 2020, Zhang *et al.* [18] done the work to show, the simultaneously enhanced electrical conductivity and mechanical properties of Al were successfully achieved in this study by using graphene as the reinforcement. The properties such as electrical conductivity, tensile strength, and elongation of graphene/Al nanocomposite were increased by 2.1%, 17.3% and 35.4% respectively than that of pure Al. The observed advance of trade-off tendency between mechanical properties and electrical conductivity was due to the homogeneously dispersed graphene in nanocomposite and formation of high-quality graphene/Al interfaces. This study shares new approach for preparing high-strength and highly-conductive graphene/Al nanocomposites.

In year 2018, Bai *et al.* [19] explored in this paper, change rules between the compressive strength as well as electrical resistivity and the silica fume content. Silica fume can not only act as an effective dispersing agent to improve the dispersion of graphene, but also increase the interfacial strength between graphene and hydration products. The suitable amount of silica fume ease the pore refinement of cement paste. In the case of composite containing low content of graphene, addition of appropriate amount of silica fume will boost the mechanical and electrical performances. However, the extra amount of silica fume had a bad impact on these properties. Combination of low amount of graphene and appropriate amount of silica fume improved the compressive strength by a significant level. As for electrical properties, relatively more amount of silica fume will result in drop of electrical resistivity of the composite. Incorporation of high amount of graphene and sufficient amount of silica fume helped in achieving superior electrical conductivity of the composite.

In year 2019, Bhanuprakash *et al.* [20] fabricated Hierarchical epoxy composites with Graphene Oxides(Gos) coated carbon fibres through VARTM technique and studied for their mechanical and electrical properties according to the relevant ASTM standards. A simple and easy EPD technique was applied to achieve continuous and homogenous coating of GOs and rEGOs onto the CF surfaces. Further, GOs coated CFs were thermally annealed in a vacuum oven at 200°C for 2hrs to create thermally reduced GOs-CFs (TrGOs-CFs). Coating of GOs onto the carbon fibres had remarkably enhance the interfacial interactions between the fibres and the matrix resin, where ILSS properties of their composites exhibited an augmentation of 47% with GOs coated CFs, 44% with TrGOs-CFs and 41% with rEGOs-CFs. The coating of GOs has improved surface properties such as surface roughness, surface area and surface energies, which gave rise to affinity between the fibres and the matrix, in turn, improved the interfacial adhesion. Electrical conductivity measurements of composites demonstrated a substantial improvement of 127% in through-thickness conductivity values for TrGOs-CFs. It is confirmed that the treatment of thermal annealing caused defunctionalisation of GO by partially rehabilitating the graphitic structure in material, thus, a network of conductive channels was realised in the system which in turn intensified the conductivity values of their composites.

In year 2021, Osman *et al.* [21] explored the synergy between the outstanding thermal and mechanical properties of graphene with the excellent insulation and mechanical properties of alumina was found to be a promising hybrid filler to improve the thermal insulation and mechanical properties of polymers. By the means of ultrasonication, seven different ratios of RGO and alumina were immersed into the epoxy polymer to decide the best desirable ratio between both to produce multi-functional epoxy packaging materials. Although the epoxy polymer filled with a constant filler loading at 1wt%, the properties are changed significantly by manipulating the ratio of the RGO-alumina hybrids. By using a decision-making tool, it was discovered that the ratio of 6:4 between RGO and alumina was the supreme. At 6:4, the thermal conductivity was uplifted by 23.4%. While, the insulation properties of epoxy composites were retained remarkably as variation to RGO/epoxy composites. Besides, the tensile strength was enhanced by 22.56%. Also, the storage modulus was enhanced by 4.6% compared to the pure epoxy. Generally, the insertion of alumina nanoparticles between the graphene sheets not only subdues the electron transfer but also reduces the accumulation of graphene sheets, which is the major reason for better properties of the hybrid/epoxy composites in variance to graphene/epoxy composites.

III. EXPERIMENT PROCEDURE

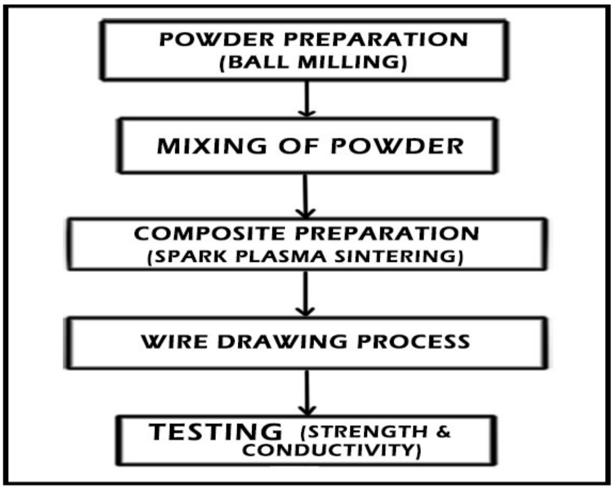

Fig. 1. Procedure to be followed for drawing CuG wire

A. Sample Powder Preparation:

The materials are bought from two different companies viz. AdNano technologies & Sarvottam Enterprises. Taking the calculated amount powder in the Petri dish. The mixture is poured in the mixing box and then in powder mixing machine with help of Steel balls into it, the Powder is properly mixed for having proper distribution in all over composition. The ratio of capital Cu: G is 99:1 i.e., 100 gram of composite have 1 gram of graphene and 99 gram of copper.

B. Sintering:

After preparation of powder, using the graphite die the sintering is done using hot press sintering (HPS) machine. The Powder material is poured into the die with lower punch act as base and using the upper punch arrangement which is fixed into fixture or supporting frame. Then the frame is placed in the sintering machine. The initial parameters are set. The initial temperature is starting from room temperature and raised to up to 600 °C or 700 °C. This is done by step wise manner. The temperature is being increase by 3°C/minute up to 100°C, after 100°C the temperature has to increase at rate of 10°C/minute. After this, the pressure of 106kg/cm2 is being applied for about half an hour. And finally, the stack like structure is prepared.

C. Wire Drawing:

This stack like structure has to be converted into elongated form and thus preheating and hammering is done for this purpose. The preheating temperature is lower than sintering temperature (below 600°C). The elongated structure has to be drawn into the wire. For this purpose, wire drawing machine is used. The one end of that elongated path is passed from the machine towards the other way where machine holds the other end and then the machine automatically draws the wire according to input given to the machine. The input is set to give the output of 1.382 mm of wire. Thus, wire is prepared successfully.

D. Testing:

The testing was done for calculating resistivity. The material wire of 1m length and diameter of 1.382 mm was taken. By using the ohm meter, the resistance was successfully calculated i.e., $1.4866\times10^{-5}\Omega$ and for traditional wire it was $1.14\times10^{-2}\ \Omega$. Here, the resistance was decreased thus increases the conductivity. Also, the coating of thermoplastic elastomer is done on the material wire.

IV. Results and Discussion

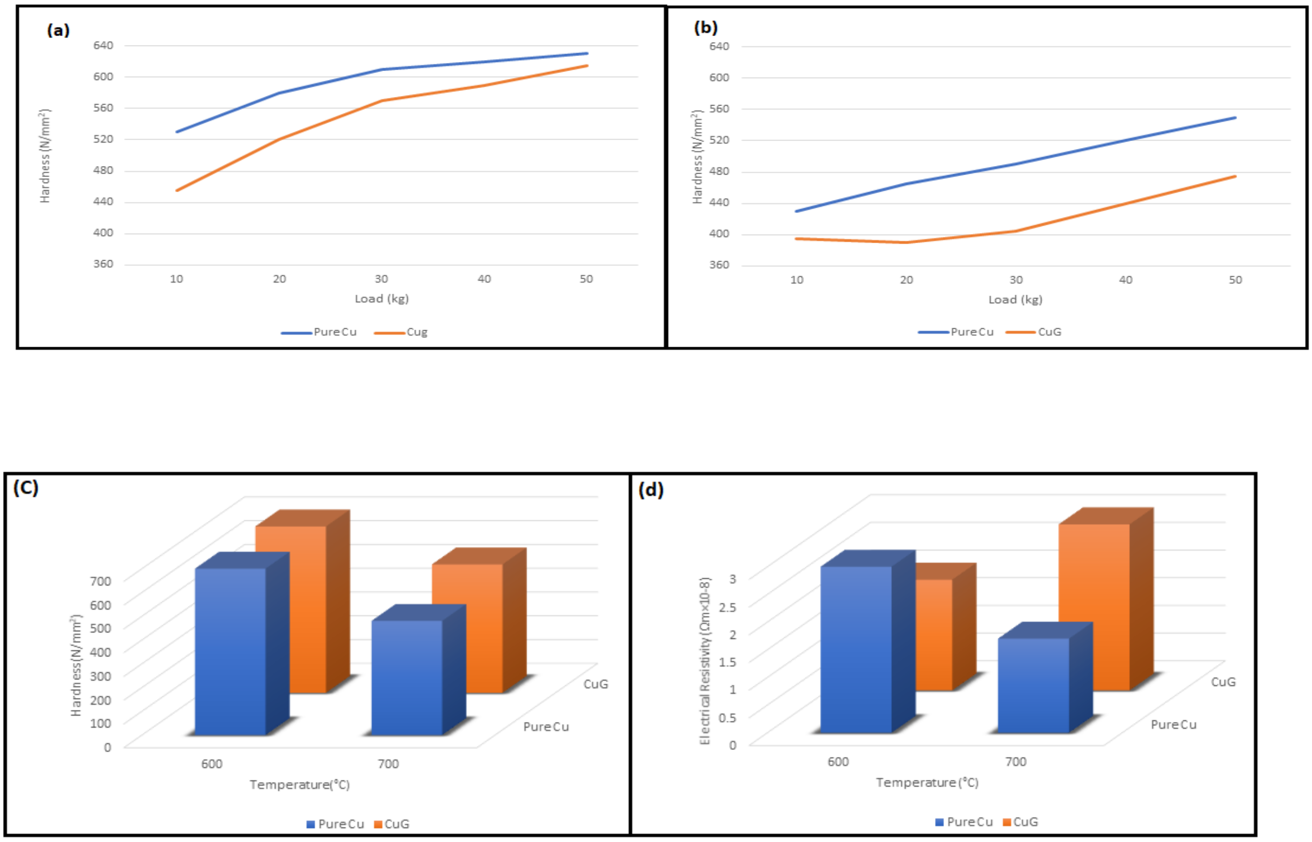

Fig. 2. (a)Hardness v/s applied load for pure Cu and CuG at 600°C, (b) Hardness v/s applied load for pure Cu and CuG at 700°C, (c) Hardness v/s applied load for pure Cu and CuG at 600°C and 700°C Using Bar graph and (d) Electrical resistivity v/s applied load for pure Cu and CuG at 600°C and 700°C Using Bar graph.

A. Characteristics of CuG wire:

As the powder of both(Cu & G) was sintered to form composite which physically appeared as a pellet size and of brownish-grey colour. The powder was sintered at two different temperatures i.e. 600°C and 700°C, they both showed different properties.

The composite sintered at 600°C showed the resistivity of 1.83×10^{-8}Ωm, and the compsite sintered at 700°C showed the resistivity of 2.22×10^{-8}Ωm. Whereas the resistivity of pure copper is 1.75×10^{-8}Ωm. at 700°C, while it is 2.23×10^{-8}Ωm. at 600°C. This concludes that the resistivity for CuG material wire is higher at 700°C than 600°C. Thus this wire can help in conducting electricity more efficiently and thus saving time.

The hardness of materail in therms of HV heated upto 600°C and 700°C was found to be 63.45 and 47.5 for the pure one and for the composite of Cug was found to be 63.3 and 55.2 respectively while in term of Gpa for pure material heated upto 600°C and 700°C, and CuG composite material are found to be 0.64,04.482, 0.621 and 0.54 respectively.

B. Future Scope:

a) Using the CuG composite wire material in circuit may improve the performance of that circuit.

b) Gold circuit wiring used in satellites increases the cost of overall project, while replacing it with thin nanosheets of this wire can reduce the cost.

c) Electric circuit boards' wiring used in computers can also be replaced with the thin sheet of this wire.

CONCLUSION

In summary, CuG wire is fabricated successfully by using the wire drawing process. The powder of G and Cu are mixed and thus homogenous mixture is formed by using ball milling and by sintering in the graphite die the stack like structure is prepared. This stack is further hammered to make it elongated by further wire drawing process the wire is drawn. By applying the coating of thermosetting plastic, the wire is insulated. Experimentally the resistance is reduced by 18%, thus enhancing its conductivity.

NOTE: The result we found is based on the experimental condition provided which may vary when dealing in actual condition.

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