International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Development of Copper-Chromium Electrical Contact Materials by Powder Forging

Gotkhindikar Nitin N.[1], Dr. V. V. Dabhade[2]

[1, 2] Indian Institute of Technology (Department of Metallurgical Engineering & Material science), Roorkee, Uttarakhand, India

Abstract: ***The electrical contacts form an integral part of circuit interrupters for which the desirable properties of contact materials are high mechanical strength, high electrical and thermal conductivity, high wear and weld resistance. Despite of different manufacturing techniques like electro-slag crucible melting, vacuum arc smelting, vacuum continuous smelting etc.; the Powder Forging being a solid state process and having high densification factor is an efficient method for the production of electrical contact materials. In the present study Cu-Cr30 wt. % alloys are prepared from elemental powders by sinter-forging. Nb is also added in varying quantities to improve the electrical and mechanical properties and the forging temperature is also varied .The variation in contact material properties due to these changes are tabulated and compared.***

Keywords: Powder forging, SEM, XRD, EDS, Elemental mapping, Sinter-forging etc

1. Introduction

Over past 50 years, contact materials based on Cu-Cr have become established for the use in vacuum interrupters for medium voltage switches. They are used as contactors and circuit breakers within a voltage range of 1 kV to 75 kV. The vacuum circuit breaker is such a kind of circuit breaking instrument where the arc quenching occurs in vacuum. For higher voltages vacuum technology has been developed but not commercially viable [1]. For current carrying contacts which material used plays vital role in performance of vacuum circuit breaker. Prerequisites of electrical contact materials therefore are best electrical and mechanical properties.

Desirable properties of electrical contact materials can be broadly be stated as, high mechanical strength, minimum gas content, high weld resistance, optimum vapor pressure, low thermionic emission, low erosion, high thermal and electrical conductivity, high withstand voltage [2].The metals, satisfying these properties are Copper (Cu), Gold(Au) Silver(Ag), Tungsten(W).By alloying these metals to other elements make them fit for use by overcoming weaknesses.
Copper suits for the application because of its high electrical and thermal conductivity, but it has strong tendency to form the weld. Tungsten is efficient thermionic emitter and Silver and Gold are very expensive [2]. Some of the desirable properties for electrical contact materials are satisfied by Cu like high electrical and thermal conductivity, minimal gas content, low thermionic emission except weld resistance and mechanical strength of Cu is low. By alloying one can overcome these drawbacks. Strengthening of Cu can be achieved by alloying with Zn,Cr,Bi,W,Te,Pb which in turn increases the hardness; reduces the conductivity of the alloy. On the relative scale, Cu alloys are cheap [2, 3].

Due to inadequate solubility of Chromium in copper in solid state, results in high thermal and electrical conductivities of a material. Cr precipitates in the form of dispersed fine particles. Another highly beneficial property of these contact materials high affinity to oxygen for Cr component in contact material which results in absorption of any oxygen content released during switch process in turn helps to protect vacuum in the interrupting chamber during service period of this device [4].

Owing to some of the properties mentioned above it is not that much easy to manufacture high quality Cu-Cr electrical contacts. A range of production processes are adopted for the manufacturing but mostly powder metallurgical processes. Most widely used procedure is mixing chromium with copper powder, compacting the mixture, sintering the green shape below the melting point of the Cu to produce blank for contact pieces. Another method can be varied as skeleton of Cr is sintered and Cu is infiltrated. Cu in liquid phase produces extremely strong bond between both the constituents [4].

Other methods like Vacuum continuous casting, Electro-slag crucible melting, Vacuum arc smelting, Explosive compaction are also the alternative production processes [1, 5]. Powder forging (P/F) is the technique to manufacture components essentially free from internal porosity. The density, mass and shape of the preformed component are controlled strictly to ensure consistency in the characteristics of the final forged component. The preform is generally sintered with conditions for the reduction of nonmetallic inclusions. The reheated sintered preform, placed in the forging die, and forged to aim at full density. Other advantages of powder forging are

1) Easily possible to produce Cu-Cr contact materials because with some processes difficulty arises due to large difference in their melting points(Cu-1091°C,Cr-1869°C) and densities(Cu-8.96g/cc,Cr-7.16g/cc).
2) It is a total solid state process and density around unity can be achieved by the process [6].

The aim of this study is to develop Cu-Cr electrical contact materials which involves powder forging of Cu-Cr .Powder forging was carried out by following premixing, compaction, sintering followed by forging. The detailed study of microstructural analysis, hardness and conductivity measurements were carried out for optimization of properties of contact material.

2. Literature Review

Some of the desirable properties for electrical contact materials are satisfied by Cu like high electrical and thermal conductivity, minimal gas content ,low thermionic emission except weld resistance and mechanical strength of Cu is low[2]. By alloying one can overcome these drawbacks. Strengthening of Cu can be achieved by alloying with Zn,Cr,Bi,W,Te,Pb which in turn increases the hardness; reduces the conductivity of the alloy.On the relative scale,Cu alloys are cheap.

While preparing the electrical contact materials,Cu is the major constituent when alloying with the variety of metals.With non refractory metals [Cu-Bi, Cu-Zn , Cu-Sn] alloy shows very low chopping current.Though, resistance to weld of such alloy is very high; they show very high contact erosion.Withstand voltage is also very low and mechanical properties are also somewhat reduced.

With refractory metals like W; alloy shows low chopping current as well as low contact erosion and current interrupting ability is also very high but they are very expensive.

Table 2.1.1: Qualitative comparison of different kinds of cu alloys [6]

Material	Gas Content	Resistance to erosion	Withstand Voltage	Choppin g current
Cu-Cr	Low(+)	Very high(++)	Very high(++)	Low(+)
Cu-W	Low(+)	Very high(++)	High(+)	High(-)
Cu-Bi	Very low(++)	Very high(++)	Low(-)	Very low(++)
Material	Ionization Energy	Electrical Conductivity	Smoothness on Contact Surface	Breaking current
Cu-Cr	High(+)	Very high(++)	High(++)	Very high(++)
Cu-W	High(+)	High(+)	High(++)	Low(-)
Cu-Bi	High(+)	Very high(++)	Low(-)	High(+)

With the semi refractory materials like Cr, alloy has low contact erosion, +high voltage withstanding capacity,high resitance to weld.These properties leads to high current interruption performance.

Properties of material affects it's performance as well as limitations.So the best one will also have some limitations on relative scale.From Table 2.1.1 it is evident that Cu-Cr alloys are fit for use for preparing electrical contacts.The desirable characteristics of this alloy are Current interrupting ability,high withstand voltage,high resistance to weld during arcing.

The further improvement inalloy can be done by changing the composition of an alloy i.e Cr content. Increase in Tensile strength. Hardness,Withstand voltage,Solid solubilty of Cr increases but at the expense of thermal and electical conductivity.circuit breaking ability,density decreases.
W.P.Li carried out an experiment with varying compositions of CuCr alloy with change in Cr content.Table 2.1.2 and Fig 2.1. shows outcomes of his results.It is proved from his results that Cu-Cr 30 composition is well suited for electrical contact materials.

Table 2.1.2: Summary of test results with varying Cr content[7]

Cr wt.% in CuCr		5	10	15	20	25	30	35	40	45	50	75
Electrical Conductivity (%IACS)		64	61	56	51	46	40	36	31	26	22	<17
Brinell Hardness (HB500)		54	52	56	59	58	64	66	42	44	61	66
Total VI Resistance (μΩ)		22	23	23	25	25	29	27	30	30	34	46
A.C. Withstand Before Arcing (kV) (1)		80	80	80	80	80	80	80	80	80	80	80
A.C. Withstand After 100% Current (kV) (1)		70	80	68	80	80	80	80	80	80	80	70
Impulse Voltage Withstand Before Interruption Test (2)	+kV	204	221	221	221	221	204	221	187	204	221	221
	-kV	238	255	221	221	221	170	255	238	238	204	221
Impulse Voltage Withstand After Interruption at 100% Current (2)	+kV	115	187	204	255	204	204	221	187	221	221	128
	-kV	128	221	128	204	221	170	255	238	221	170	153
Normal Interruption at 75%Current (3)		100	100	100	100	100	100	100	100	100	100	75
Normal Interruption at 100%Current (3)		0	100	91	88	100	100	100	88	100	75	0
Normal Interruption at 108%Current (3)			50		50	100	100	75	50		75	
Normal Interruption at 116%Current (3)			0		0	75	100	0	0		0	
Normal Interruption at 122%Current (3)			0		0	33	75	0	0		0	

(1) A.C. power frequency withstand voltage. Tested only up to the 80 kV rating
(2) Lightning Impulse Voltage withstand. Highest voltage passed using the ANSI 3x3 test method
(3) Percentage of successful interruption with an arcing time shorter than 1 full cycle

2.1 Copper-Chromium Phase diagram

The equilibrium diagram for the Cu-Cr system is one of the eutectic type, with flat liquidus and complete miscibility in the liquid state. The equilibrium phases in the system are 1) The liquid L, 2) The fcc solid solution (Cu) with maximum solubility of approximately 0.89% at Cr at 1077°C, and 3) the bcc solid solution (Cr) with negligible solubility of Cu below the eutectic temperature (1077°C).

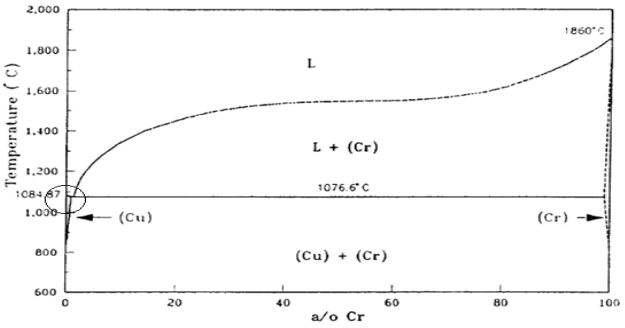


Figure 2.1: Cu-Cr phase diagram [10]

At 30 wt. % of Cr, there is fine and homogeneous distribution of Cr in Cu matrix; which results in excellent electrical performance of an alloy.

2.2 Developing trends in Copper-Chromium contact materials

i) Size and distribution of Cr particles in Cu-Cr alloy:
Consistency and homogeneity in microstructure leads to improvisation in contact material properties, however refining the Cr grains will cause the chopping current falling and dielectric strength gain, but in turn increase the cost of material.

ii) Better interface between Cr and cu:
In solids interfaces plays dominant role influencing their electrical, mechanical and magnetic properties. Refining Cr grains and increasing interface area, interruption performance can be increased by virtue of interface structure and joint strength optimization [11].

iii) Addition of third element to the system: Further endurance, resistance to erosion and weld can be achieved by multiple effects of third element addition.

iv) Advance manufacturing technique: Adopting Surface techniques processes like vacuum plasma metallurgy (VPM) performance level can be increased.

2.3 Previous researches

The study reveals that Cu-Cr 30 is the best suited materials for the manufacturing of electrical contact materials. Here, the effect of particle size variation of Chromium content has not been fully explored while going through powder forging process. The aim of our study to reveal microstructure analysis, hardness & conductivity measurements to optimize the properties of electrical contact materials.

3. Experimental Setup and Procedure

Detail plan of work involved in Development of Cu-Cr electric contact materials by powder forging is shown in Fig 3.1.1 Cu-Cr30 electric contact materials were prepared by mixing elemental powders in appropriate ratios ,compacting them (green compact) followed by sintering in reducing atmosphere. Then samples are hot forged, quenched and annealed .Tests were carried out for electrical and mechanical properties of material; as well as microstructure analysis were done simultaneously.

Sr No	Name of the research and author	Work area / Compositions used	Outcomes
1	Microstructure and properties of Cu-Cr contact materials with different Cr content [2011] XIU Shi-xin, YANG Ren, XUE Jun	CuCr25,CuCr30, CuCr40	With increasing Cr content hardness, Tensile strength increases while electrical conductivity decreased.
2	Effects of Cr content on the interruption ability of Cu-Cr contact materials [2000] W.P.Li, R.L.Thomas	Cr content varied within 5 to 75% and tested for brinell hardness, total VI resistance, Normal interruption current, Voltage withstand	Cr content of 30% gives best interruption performance as well as optimum properties.
3	Properties of Cu-Cr contact materials with low Cr content and fine particles[2009] CAO Hui.Wang ya ping	Cr content tested for 15,21 29%	Electrical conductivity increases with decrease in Cr content
4	Rieder,Vienna Technical University [2001]	Cr % varied from 25% to 50%	Chopping behavior and breakdown voltages are improved when fine grain Cr powder is used.
5	Electrical conductivity of Cu-Cr alloys[1998] Zhang Tie ,He Junjia, Zou Jiyan	CuCr25,CuCr50, CuCr75	Conductivity decreases with increase in Cr content

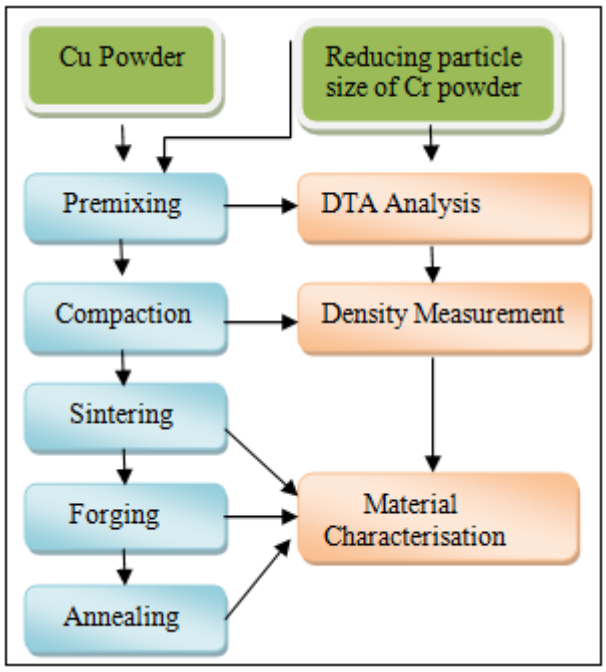


Figure 3.1.1 Typical Flow chart for experimental work

The specific characteristics of elemental powders of copper and chromium are given in Table 3.1.1

Table 3.1.1 Specific powder characteristics

Sample	Purity	Density (g/cc)	Particle size
Cu powder	99.99%	8.96	-325 mesh
Cr powder	99.99%	7.19	-400 mesh

The elemental Cu and Cr powders are characterized by XRD analysis, SEM (Scanning Electron microscopy), EDS (Energy Dispersive Spectroscopy).This characterization is carried out to analyze phases present in it, shape and size of powders, and purity of powders respectively. Particle size is measured in SEM and powders are applied on stubs with gold coating before inserting it into scanning electron microscope. The aim of milling was reduce particle size of Cr powder particles up to 5 micrometers. The milling was carried out in Planetary ball mill, RETESH PM 400/2.A pair of hardened steel jar is used, in which Cr powder was inserted 30 gms in each jar. Hardened steel balls were used for milling of powder. Other milling parameters are given in below.

Table 3.1.2 Milling parameters

Speed of Milling	250 rpm
Time period	1,2,4,6.5 hrs.
Ball to Charge ratio	10:1
PCA	Toluene
Wt. of Cr powder	30 gm.

Composition of Cu-Cr alloy was fixed to 70:30.The ball milled Cr powder of different particle sizes and Cu powder were weighed accurately on electronic weighing balance machine and mixed manually in mortar pestle for 1 hour per

sample. Weight of the powder used for making single pellet came out to be 5.1 gm. and that of die compact was 86 gm.

Differential thermal analysis (DTA) was carried out for CuCr30 mixture. EXTAR TG/DTA 6300 instrument was used to analyze the liquid phase formation. Essential parameters are given in the table below

Table 3.1.3 Testing conditions for DTA

Sample weight	10.760 mg
Reference name	Alumina powder
Reference weight	10.500 mg
Rate of heating	10°/min
Max. temperature	1400°C
Atmosphere	Ar gas(200 ml/min)

Liquid phase formation can be found out by DTA analysis. To find out sintering temperature of mixture CuCr30, it had to be kept below the melting point of one of the constituent in the mixture to prevent any chance of mixture entering into to liquid phase sintering.

After pre-mixing of powders, pellets were prepared on hydraulic press using cylindrical die. Also, green compacts were produced by hydraulic press by uniaxial pressing in the rectangular die. Springs underneath had doubled the effect the pressure applied from the top. Green compacts produced are characterized and density calculations are carried out.

Sintering of green compacts was carried out in tubular furnace in a reducing atmosphere to prevent kind of oxidation during heating of the samples. Reducing atmosphere was generated by providing premixed gas. The gas mixture is passed continuously throughout the process and was verified by bubbles coming out of end of the tube. Continuous water circulation was taken care of to avoid overheating of end caps of the tube. To control the heating rate and to maintain constant temperature during heating microcontroller is used.

Table 3.1.4 Parameters for sintering

Sintering temperature	1050 ^{0}C
Sintering time	40 minutes
Pre-heat rate	20^0/ min
Sintering atmosphere	H_2(20%)+ Ar(80%) gas

Hot forging of sintered compacts was carried out at 1050 ^{0}C in friction screw press with the use of rectangular die. The density of compacts was expected to be increased during forging. Forged samples were quenched in cold water and were sent to material characterization to study the effect of forging.

The aim of annealing operation was to increase electrical conductivity. Operation was carried out in the same tubular furnace which was used for sintering. Gas mixture was used to prevent any chance of oxidation of samples. Soaking is carried out at 1000°C and allowed to cool slowly in furnace.

Table 3.1.5 Parameters used in annealing

Annealing temperature	1000 ^{0}C
Annealing time	1 hour
Pre-heat rate	20^0/ min
Annealing atmosphere	H_2 gas

3.1 Material Characterization

Characterization of material consists of inspecting various electrical (conductivity) and mechanical (density, hardness, ultimate tensile strength) properties of material. It also involves XRD analysis as well as microstructure examination with SEM, EDS, Optical microscopy.
Density calculation:

(a) Pore free theoretical density:

$$\rho_{th} = \frac{1}{\frac{wCu}{\rho Cu} + \frac{wCr}{\rho Cr}}$$

where, ρ_{th} = theoretical density
wCr = wt % of Cr
wCr = wt % of Cr
ρ_{Cu} = density of Cu
ρ_{Cr} = density of Cr

(b) Green compact densiy:
Green Compact dimensions were measured br micrometer screw gauge and compacts were weighed on electronic weighing balance accurately.By using the formula below green compact density was calculated

$$\rho g = m /(l*b*h)$$

where ; $\rho_{g=}$ green compact density
m = mass of the compact
l = length
b = breadth
h = height

Rockwell hardeness testing method wad adopted to calculate the hardness of different samples with the use of Rockwell B scale. DC-11 M instrument was used to measure electrical conductivity. Measurements were done at various points of the surface of the sample and the average value was taken as final reading. Optical microscope and Scanning electron microscope were used to analyze the detailed microstructure of samples. Sample preparation was done before analyzing the microstructure

4. Results and Discussion

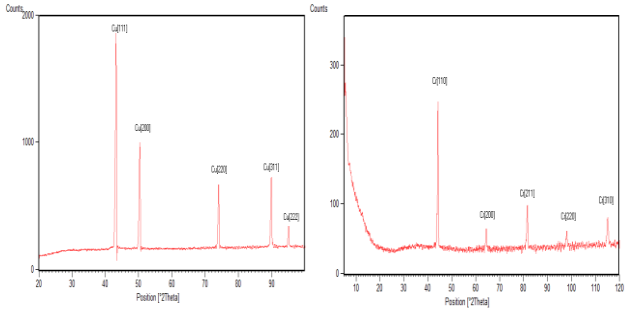


Figure 4.1.1 XRD Pattern Of Cu (1) & Cr (2) powder

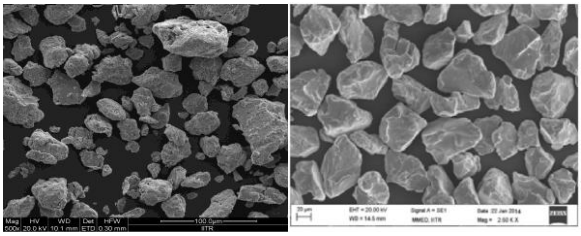
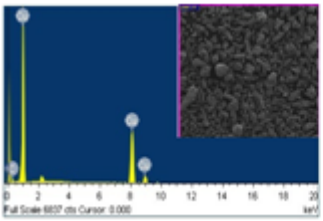
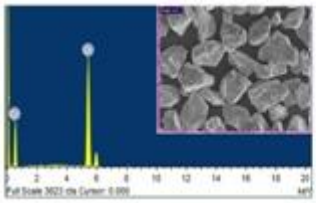


Figure 4.1.2: SEM Imane Of Cu (1) & Cr (2) powder



Element	Weight %	Atomic %
C K	9.09	34.60
Cu K	90.91	65.40
Total	100.	100.0

Figure 4.1.3: EDS analysis of Cu powder



Element	Weight %	Atomic %
Cr K	100	100
Total	100.	100.0

Figure 4.1.4: EDS analysis of Cr powder

Peaks of [111],[200],[220],[311] and [222] characteristic planes of FCC copper were shown in XRD plot with good intensities. The shape of the powder is random and size less than 40 µm. Purity of powder is confirmed by EDS. Little amount of carbon present due to the carbon tape pasted on stub on which mounting of powder was done.

Peaks of [110],[200],[211],[220] and [310] characteristic planes of bcc Cr were shown in XRD plot. Size of the powder is less than 50 µm.

4.1 DTA analysis for CuCr30

To determine sintering temperature the DTA curve was useful. At temperature around 1100°C curve showed an endothermic peak. 220 mJ/mg heat energy is absorbed at this peak, which means liquid phase was formed at this stage. Therefore, below temperature 1100° C densification should take place. To restrict the sample to enter in liquid phase sintering temperature was decided as 1050° C.

Table 4.1.1 Cr Particle size at different milling time intervals

Milling time (hrs.)	Particle Size (µm)
0	44
1 Hr.	32
1Hr 45 min	24.7
4 Hrs.	11.2
6 Hrs. 30min	4.7

4.2 Measurement of Densities:

Table 4.2.1 Values of densities of different samples

No.	Sample	Green Compact Density		Sintered Density(gm/cc)		Densification Parameter	Forged density		Theoretical Density
		gm/cc	Relative %	gm/cc	Relative %	%	gm/cc	Relative %	gm/cc
1)	CuCr30 1 SNF	5.48	65.70	5.88	70.60	13.98	7.92	94.96	8.34
2)	CuCr30 2 SNF	5.65	67.86	6.13	73.54	17.84	7.98	95.68	8.34
3)	CuCr30 3 SNF	5.85	70.14	6.27	75.26	16.86	8.02	96.16	8.34
4)	CuCr30 4 SNF	6.12	73.38	6.73	80.70	27.47	8.03	96.28	8.34
5)	CuCr30 5 SNF	6.66	79.96	7.24	86.84	34.52	8.11	97.24	8.34

SNF: Sintered at 1050°C and Forged at 1050°C.

CuCr30 1,2,3,4,5 are Cu 70% & Cr 30% with Cr powders with as received,1hr,2hrs,4hrs,6.5hrs ball milled.

Difference in green densities of various samples is observed due to reduction in Cr particle size. During sintering reduction in pore size takes place due to diffusion process, which leads to increase in the density of the material. Voids were filled up during sintering process and bond strength was increased. Green compact density was around 65% pure CuCr30 sample with no size reduction of Cr particle, which was increased up to 94.96%. After forging.

Further porosity was decreased with forging operation which in turn increased the density of sintered samples. Density around 95-99% was achieved in further forging operation.

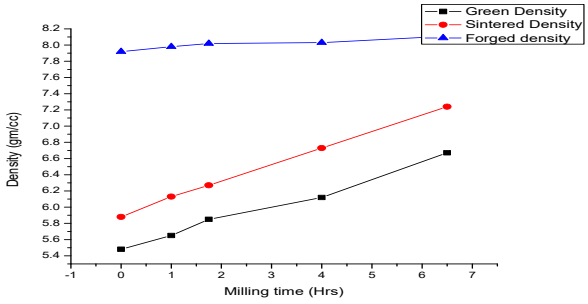


Figure 4.2.1: Variation in different densities with milling time

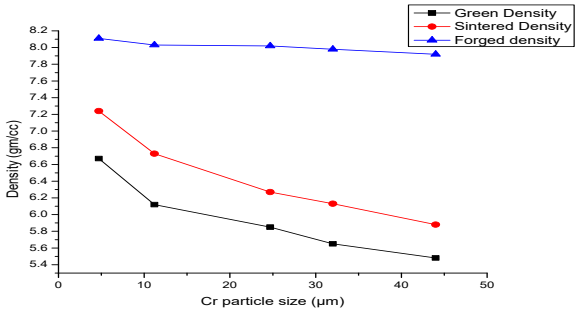


Figure 4.2.2: Variation in different densities with Cr particle size

4.3 Measurement of Hardness:

Table 4.3.1 Values of hardness for sintered, sinter-forged and annealed samples

Samples	Hardness [HRB]	Samples	Hardness [HRB]	Samples	Hardness [HRB]
CuCr30 S1	48	SNF1	70.4	A1	43.9
CuCr30 S2	57.6	SNF2	74.6	A2	48.1
CuCr30 S3	59.4	SNF3	75.1	A3	49.7
CuCr30 S4	61.8	SNF4	75.4	A4	50.6
CuCr30 S5	62..6	SNF5	76.2	A5	52.2

A: Annealed S: Sintered SNF: Sinter-forged.

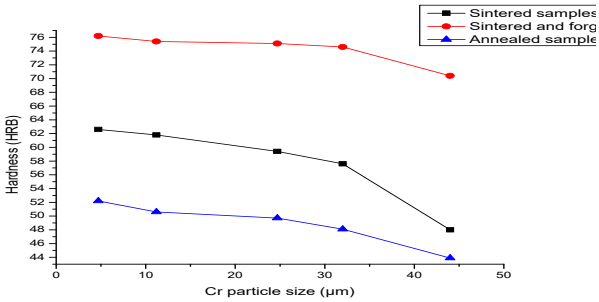


Figure 4.3.1: Hardness of different samples Vs. Cr particle size

Grain refinement was occurred during forging which increased hardness during forging, while during annealing grain growth was caused leads to soften the material and in turns, reduce the hardness of the material considerably. Hardness of sintered sample with 6.5 hrs. Ball milled Cr powder increased up to 76.2 HRB. Figure shows steep curve during first 1hr milling time and its effect was less pronounced after that and levels off ; may be due to steady state condition is achieved. With milling time due to grain size refinement and increase in precipitation hardening effect, increase in hardness was achieved.

4.4 Measurement of Electrical conductivity:

Table 4.4.1 Values of Conductivity for sintered, sinter-forged and annealed samples

Samples	Conductivity [%IACS]	Samples	Conductivity [%IACS]	Samples	Conductivity [%IACS]
CuCr30 S1	38.27	SNF1	24.45	A1	41.20
CuCr30 S2	33.21	SNF2	21.33	A2	40.65
CuCr30 S3	31.98	SNF3	20.75	A3	39.73
CuCr30 S4	29.78	SNF4	18.11	A4	39.62
CuCr30 S5	30.67	SNF5	18.62	A5	39.55

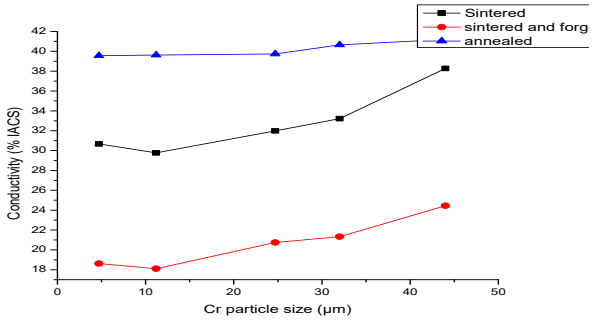


Figure 4.4.1: Conductivity of various samples Vs Cr particle size

Conductivity of the forged samples was reduced than that of sintered samples may be due to inhomogeneity caused by the imperfections during hot working. Harder Cr grains accumulated at the edges causing inhomogeneous structure. During annealing by refining grain structure making homogeneous and internal stress relieving.

Conductivity decreased sharply up to 4hrs milling time and then increased slightly for sintered and sinter-forged samples. Conductivity as a function of milling time decreases due to i) density of electron scattering centres increases and lattice imperfections ii) small lattice space of small particles and large interface area, may be due to increased solubility of Cr. iii) Impurities like Fe, O increases with increase in milling time. iv) Internal strains [4].

During annealing there is less significant effect of particle size on conductivity of samples. Gain in conductivity after 4 hrs. of milling is may be due to precipitation of Fe.

4.5 Micro-structural analysis

Sintered samples:

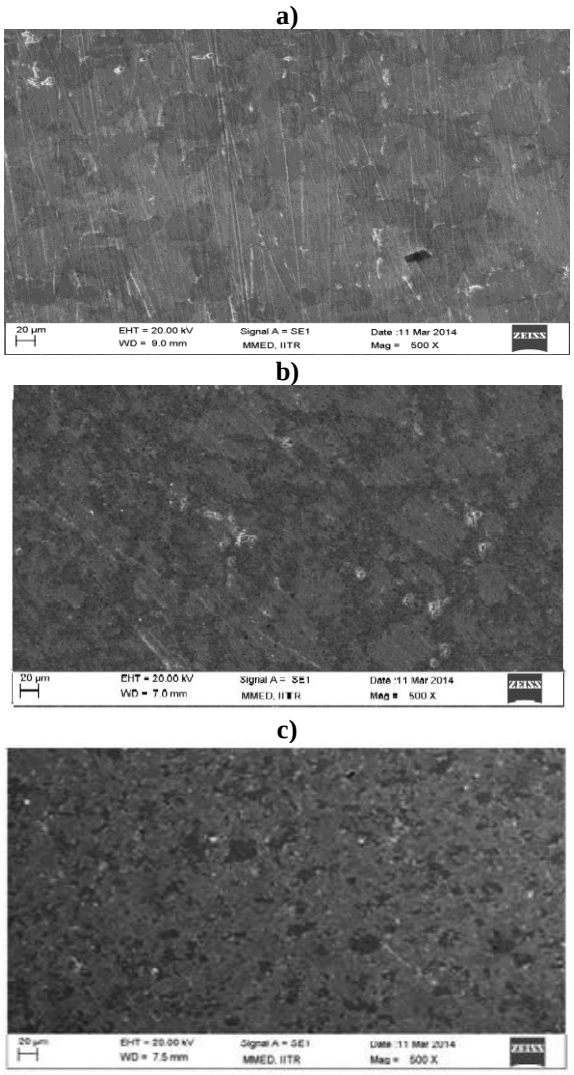
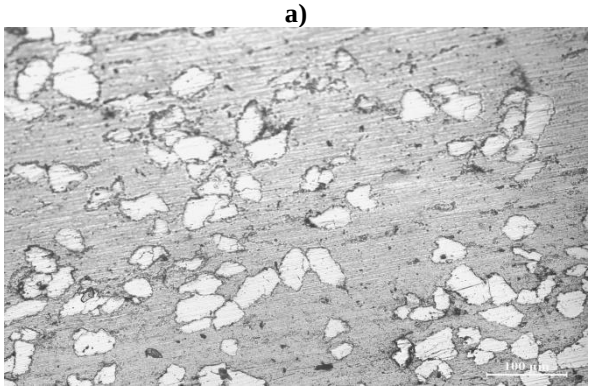


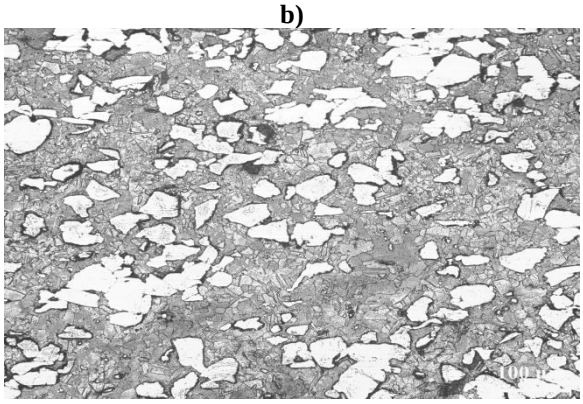
Figure 4.5.1: SEM Images of sintered CuCr30 with a) as received b) 2 hrs. Ball milled c) 6.5 hrs. Ball milled Cr powder

Sinter-forged samples:

a)



b)



c)

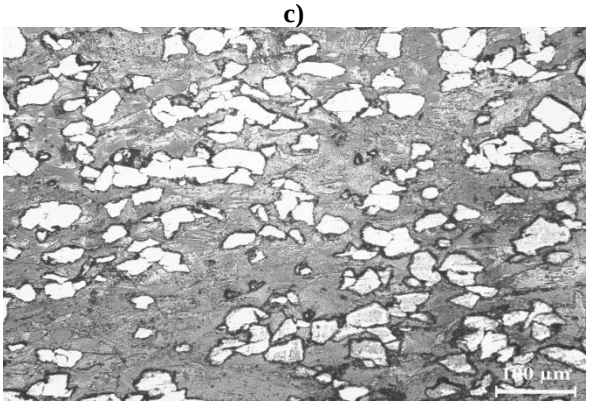
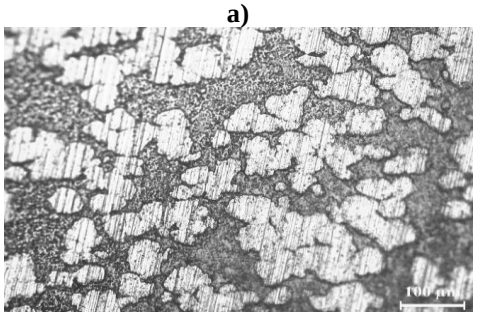


Figure 4.5.2: Optical Micrographs of sinter-forged CuCr30 with a) as received b) 2 hrs. Ball milled c) 6.5 hrs. Ball milled Cr powder

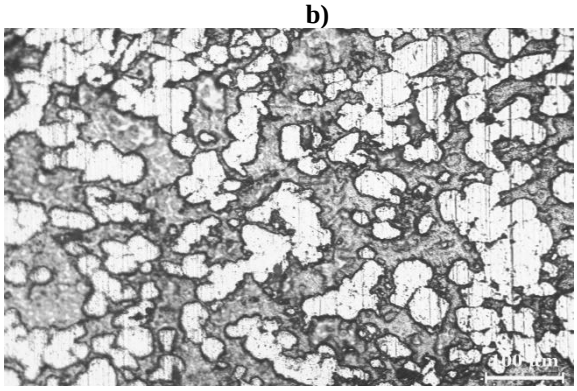
From Fig. 4.5.1 and Fig 4.5.2 shows the reduction in particle size of Cr and Cr particles are not uniformly dispersed during forging which results in inhomogeneous structure. Since the density of the sintered compact was increased up to 97.24% which earlier was up to 86%, due to further pore size reduction after forging.

Annealed samples:

a)



b)



c)

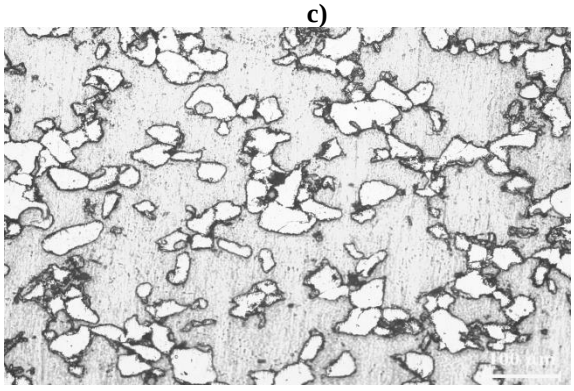


Figure 4.5.3: Optical micrographs of annealed CuCr30 a) as received b) 2 hrs. Ball milled c) 6.5 hrs. Ball milled Cr powder.

Fig.4.5.3 shows that grain growth occurred during annealing which softens the material increasing its electrical conductivity.

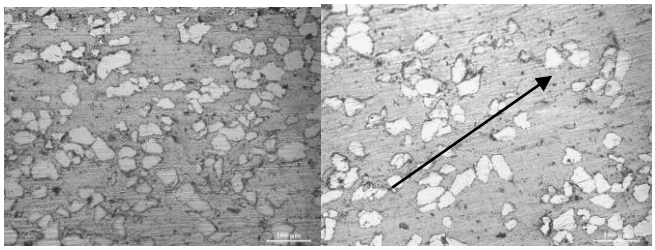
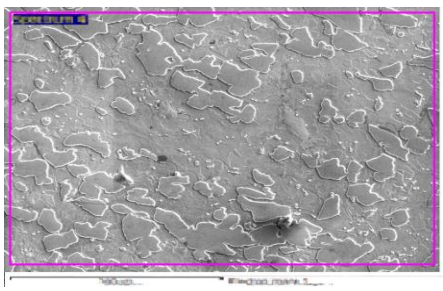
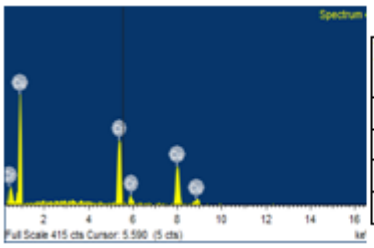


Figure 4.5.4: Sinter-forged CuCr30 in longitudinal (left side) and transverse plane (right side)

Fig 4.5.4 shows the grain shape observed in two planes .Bulged type grains were observed in longitudinal plane due to pressure applied while grains are elongated in transverse plane. So it is evident that refinement of grains occurred during forging.





Element	Weight %	Atomic %
Cu K	75.35	71.71
Cr K	19.98	23.23
Fe K	4.67	5.06
Total	100.00	100.00

Figure 4.5.5: EDS analysis of sinter-forged CuCr30 6.5 hrs. Ball milled Cr powder

From Fig.4.5.5 it can be concluded that with milling time Fe content increases and due to lack of consistency in microstructure there is variation in electrical and mechanical performance from expected values.

Elemental mapping of CuCr30 gives relative proportion and distribution of Cu and Cr along the surface of the specimen.

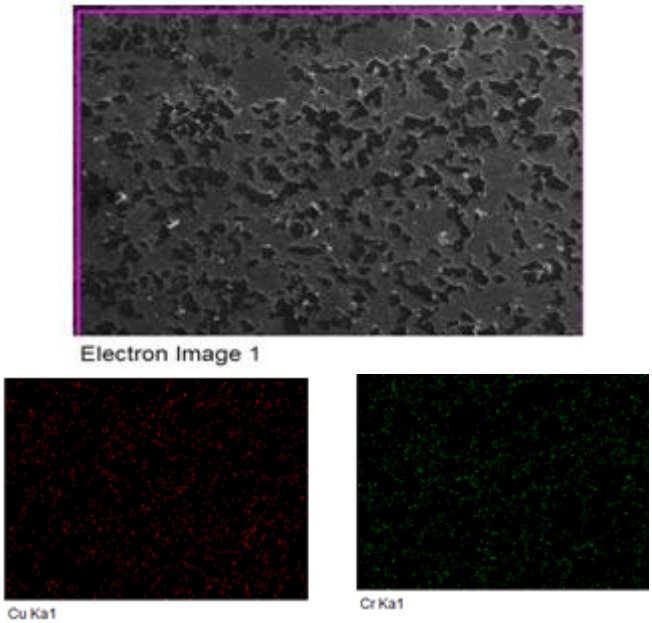


Figure 4.5.6 Elemental mapping of CuCr30

5. Conclusions

The aim of our project is to enhance the mechanical and electrical properties of electrical contact material. It has been achieved for certain extent as mechanical properties like density, hardness were good enough but electrical performance was compromised.

1) Green compact and sintered densities were increased with reduction in Cr particle size.
2) Appreciable increment in relative density as well as densification factor was observed after forging.
3) Increase in hardness observed during sintering followed by forging due to grain refinement.
4) Hardness increased very fast during 1hr ball milled Cr powder sample ,its effect became less pronounced after and then levels off maybe due to steady state condition is achieved.
5) Reduction in hardness observed during annealing due to grain growth occurred during annealing which lead to softening of material.
6) Reduction in conductivity was observed in sinter=forged material due to grain refinement while in annealing conductivity is increased due to grain growth.
7) Conductivity of sintered and sinter-forged samples decreased continuously up-to 4hrs milling time .One of the reason behind this could be increase in impurities like Fe, O.
8) decreases conductivity and other one is due to small particle size electron scattering is more.
9) Slight increment in conductivity was observed after 4 hrs. milling of Cr powder maybe due Fe precipitation.
10) Impurities of Fe were observed with increase in ball milling time due to abrasion, though iron contamination is not desirable for preparing Cu-Cr electrical contact materials.

6. Acknowledgement

The authors would like to thank the management of Indian Institute of Technology, Roorkee, Uttarakhand, India for extending the help in preparation of this research paper.

References

[1] Xiu Shi-xin, Yang Ren, Xue Jun, Wang Jin-xing,"Microstructure and properties of Cu-Cr contact materials with different Cr content", Trans. Nonferrous Met. Soc. China, 2011, 21,389-393
[2] Miao, Y. Zhang and G.Liu, Current status and developing trends, of Cu-Cr manufacturing technique contact materials for VCB, IEEE, (2004) 311-314.
[3] X.S. Xin, Y. Ren, X. Jun, W.J. Xing, Properties of vacuum cast CuCr25 and CuCr25Te contact material, Trans. Nonferrous Met. Soc. China, 19 (2009) 444 - 447.
[4] Paul G. Slade, "Contact materials for vacuum interrupters", IEEE Transactions, Hybrids and packaging, 1974,10(3), 43-47
[5] Li W. P, Thomas R.L., Kirkland Smith R, "Effects of chromium content on the interruption ability of Cu-Cr contact materials [J]",IEE Trans. On Plasma Science, 2001, 29(5), 380-383
[6] W. F. Rieder, M. Schussek, W. Glatzle, and K. Erich, The influence of composition and Cr particle size of Cu/Cr Contacts on chopping current, contact resistance, and breakdown voltage in vacuum interrupters, IEEE Trans.comp., Hybrids and manuf. Tec.,12 (1989) 273 - 283.
[7] W. Li, Robert L. Thomas, and R. K. Smith, Effects of Cr content on the interruption ability of Cu-Cr contact materials, IEEE Transactions on plasma science, 29 (2001) 744 – 748.
[8] CAO Hui, Wang ya ping, Properties of Cu-Cr contact materials with low Cr content and fine particles, Trans.nonferrous Met. Soc, Institute of metal research, china, 1003-6326(2009)04-930-03
[9] Suhrit Mula, Pankajini Sahani, S.K. Pratihar, Mechanical properties and electrical conductivity of Cu–Cr and Cu–Cr–4% SiC nanocomposites for thermo-electric applications, Materials Science and Engineering A 528 (2011) 4348–4356

[10] The Cr-Cu (Chromium-Copper) system, D.J.Chakrabarti, D.E.Laughlin, Carnegie Mellon University.
[11] K. R.Anderson and J.R.Groza, Microstructural size effects in high-strength high-conductivity Cu-Cr-Nb Alloys, Metal. Matter. Trans. A, 32A (2001) 1211-1224.
[12] Xian Ai-ping,"Cu-Cr contact materials for high power vacuum interrupters [J]", The Chinese Journal of Nonferrous Metals, 2001, 11(5), 731-738
[13] C. Suryanarayana,"Mechanical alloying and milling", Marcel and Dekker Publication, 2004.
[14] Zhao Feng, Xu Hui, Yang Zhirmao, "Preparation of CuCr25 alloys through vaccum arc smelting and their properties", Trans. Nonferrous Met. Soc. China, 2000, 10(2), 321-329
[15] Frey P, Klink N, Saeger K.E.,"Metallurgical aspects of contact materials for vacuum switching devices[J]", IEEE Trans. On Plasma Science, 1989, 17(5), 734-740
[16] ASM Hand Book, Powder Metal Technologies and Application,Vol.7(1998) Hoganas Handbook No.2, Production of sintered components.
[17] V.S.Arunachalam, O.V.Roman," Powder Metallurgy-Recent Advances", Oxford & IBH Publishing Co. Pvt.Ltd, 1989
[18] M. P. Reece, "The vacuum switch Part I and Part II,"Proc. IEE, 1963, 110(4), 793-811
[19] V.V.Sathya Prakash,. Sambhasiva Rao, U. Prakash," Production of Cu-Cr alloys by in situ reduction of chromium oxide during electro slag crucible melting",Materials and manufacturing processes, 2001, 16(2), 209-217