International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

Investigation of Precipitation During Recrystallization in Two-phase Cu-0.8Cr Alloy

[1]Amit Kumar, [1]Anupam Kashyap [1]Abhishek Anand, [1]Abhijeet Kumar Jha and [2]Dr. Kishore T Kashyap

[1]Student of Mechanical Engineering, Siddaganga Institute of Technology, Tumakuru

[2]Professor, Dept. of Mechanical Engineering, Siddaganga Institute of Technology, Tumakuru-572103, Karnataka, India

Abstract- Copper-Chromium Alloy is the high strength material with high conductivity. The As-Cast microstructure will show dendrites with rich chromium precipitates in the inter dendritic region. The microstructure of the alloy will control the properties like hardness, yield strength, fracture toughness and other such properties. In the present work precipitation and recrystallisation will be studied simultaneously. Precipitation gives high strength to the alloy whereas recrystallisation will tend to soften the material. Recrystallisation occurs after deformation which brings the deformed microstructure to original state. Recrystallisation is nucleation of strain free grains in the deformed matrix. Precipitation from the super saturated solid solution results in the formation of precipitates in the matrix of copper alloy. These precipitates are dislocation barriers during slip process and enhances the strength and hardness of the alloy.

In the precipitation hardenable copper-chromium alloy the interaction of precipitation will be studied after the classic work of Hornbogen and Koster. Precipitation occurs at heterogenous nucleation sites like high angle grain boundaries, dislocations, second phase particle interfaces etc. Recrystallisation on the other hand is motion of high angle grain boundaries. Precipitation in copper-chromium alloy is before recrystallisation, during recrystallisation and after recrystallisation as we have studied by optical microscope.

Keywords- Precipitation hardening, Annealing, Recrystallization, Nucleation, Copper – Chromium Alloy

1 INTRODUCTION

Copper and its alloys are now vastly used in various manufacturing sector where good electrical and thermal conductivities are the required properties to meet the product standards. The heat treated and pure copper has extremely good electrical conductivity, and it now forms the basis for describing the electrical conductivity of conductor materials in percentage relative to its conductivity in pure copper i.e. International Annealed Copper Standard(% IACS). As we all know pure copper has excellent electrical conductivity and it is the obvious choice as a material for most electrical applications. But apart from its good conductivity it has a quite weak mechanical strength. In some electrical and thermal (conductivity) applications where mechanical strength is of little significance, and can be ignored pure copper or lightly alloyed Cu-Sn alloys have been the natural materials of choice. Generally, the strength of these alloys can only be increased by cold work. However, improving strengths from cold work have its limits due to self-annihilation of dislocation at room temperature from dynamic recovery.

Also, a vast range of rapid solidification techniques have disadvantages such as low yield and difficulty in producing the alloys in the required industrial scale which are not economical. Due to the limitations of the above methods the mechanical properties of copper-chromium alloys which are age - hardenable, may be improved via precipitation hardening by a suitable heat treatment process. In the copper-chromium alloy system, the age hardening process may lead to the formation of coherent chromium precipitates, which can produce local distortion in the copper matrix and can strengthen the alloy by increasing its hardness.

2 RELATED WORKS

In their research work during late 90's Liu and Kang produced several evolutionary results regarding properties and microstructures of Cu-Cr alloys produced by the single roller melt spinning methods [1]. According to their research findings the micro hardness of the Cu-Cr alloys can be increased by 40-50% by several aging processes at high temperatures. Their experimentation results

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

supported the coherent precipitation theory regarding the increased hardness of the alloy.

Also in the study of surface precipitation of chromium after rapid solidification processes in Cu-Cr alloys, Bizjak and Karpe concluded that precipitation formation leads to hardening and retention of electrical properties of pure copper [2]. According to them the rapid solidifications of a solid solution of Cu-Cr alloys leads to formation of supersaturated compounds. After the rapid solidification, the microstructure is quite unstable which can attain stability by several heat treatment processes. The properties of the final stabilized products depend on several heat treatment as well as several rapid solidification techniques used. Melt spinning was used to produce the rapidly solidified ribbons. The initial Cu-Cr alloys were made by vacuum induction melting of electrolytic copper with a purity of 99.9% and chromium with a purity of 99.5% in a graphite crucible, followed by casting into a steel mold. The alloy ingots were then placed in a graphite crucible and inductively heated above the melting temperature of the alloy. In order to follow the changes in the RS microstructure an in-situ measurement of the electrical resistivity was applied during the heating of alloy. The four-point measurement was used, with the contacts and wires made from platinum. The temperature and electrical resistivity were measured simultaneously, and it was improved.

In their study of the Cu-Cr alloy with nano and microscale Cr particles Hejazi, Majidi and Akbari concluded that to increase the solubility of chromium in copper matrix several rapid solidification techniques can be applied right at the casting stage itself [3]. They casted the Cu-Cr alloys in water-cooled mold to increase the Cr solubility in Cu matrix. Rapid solidification techniques have several disadvantages like low yield, difficulty in producing alloys, non-economical processes etc. These disadvantages were targeted in this water cooled molding method. They concluded that after casting the Cu-Cr alloys with this technique the resulting microstructure consists of Cu rich matrix phase, spherical Cr rich phase and lamellar eutectic phase at grain boundary areas.

The studies on recrystallisation by several authors reveals that it is the process of formation of several small defect free regions and growth of these regions into surrounding deformed material. In their study of recrystallisation, Burgers and Cahn revealed that recrystallisation occurs during manufacture of almost all the metallic materials which makes the topics of recrystallisation and nucleation important and are therefore discussed again and again by several authors [5-6].

According to study on nucleation by Doherty, the driving force for primary recrystallisation is the stored energy of previous working processes. He revealed that nucleation is a highly heterogenous phenomena that occurs mainly at special positions of the microstructure such as prior grain boundaries, deformation bands and inclusions etc. Due to its heterogenous nature he further investigated the nucleation by detailed microstructure study by the identified potential nucleation sites in the deformed material [4].

The difficulty of studying of 3-dimensional shape of sub-grains and how they change during deformation has got an immense attention from several researchers and scholars of the world in past few years. Doherty in his study of nucleation theory observed that if an equiaxed sub-grain is formed at initial stages of deformation process, continued straining would cause it to undergo the same change of shape as of the specimen. The study of the microstructure of the sections normal to the rolling plane have supported that these changes are actually occurring. But in his individual study of deformation of materials, Hu reported that in copper rolled materials pancaked shaped sub-grains were seen in a direction normal to rolling plane and these grains were drastically different and small in size as expected during deformation of their specimen. The difference of the sub-grain size change than that of their specimen in different rolling planes implies that few new sub boundaries must have been formed lying perpendicular to the rolling plane. Other studies on heavy rolled FCC metals by Ray et al for copper have confirmed Hu's observation of growth of highly elongated shape of sub-grain in the direction normal to the rolling plane.

In several detailed and comprehensive study of nucleation and recrystallisation many possible nucleation mechanisms have been proposed. Burke and Turnbull have proposed the classical fluctuation theory according to which nucleation can either be a homogenous process or a heterogenous phenomenon occurring at existing grain boundaries or other location of defects [8]. Further Cahn, Beck and Cottrell in their individual study proposed the growth of a polygonised sub-grain which has achieved an increased size and possibly larger misorientation by coalescence of several sub-grains. This is also known as Cahn-Cottrell model. In several findings recorded under

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

optical microscopy, Beck and Sperry introduced a new mechanism according to which a sub-grain of one grain adjacent to a pre-existing high angle grain boundary grows, by migration of that boundary into the boundaries of neighboring grains [7]. This theory was named as strain induced boundary migration (SIBM). Later Bailey in his individual study under electron microscopy proved the theory of SIBM in greater details at microstructure level.

Most commercial alloys cannot exist in stable nature in their homogenous solutions. They get disintegrated into several phases that are not in thermal equilibrium with each other. The same theory holds good with copper alloy solutions also. As discussed earlier due to the increasing demand and cost of copper alloys the studies related to their stability has drawn several interests from researchers all over the world. In their study of Recrystallisation of two phase alloys, Hornbogen and Koster revealed several details of effects of particles and precipitation on recrystallisation in greater details. According to them in a supersaturated alloy particle of the second phase precipitates in same temperature range in which recrystallisation can occur [9].

The present research work aims for studying the interaction of precipitation with recrystallisation in the copper-chromium alloy and suggest further modifications in the microstructure of the alloy which would help in obtaining the optimum required properties regarding the alloy. Precipitation and recrystallisation exert a mutual influence on each other. Precipitating particles hinders the rearrangement of dislocations which is quite important for promoting recrystallisation. Cu-Cr alloys according to the recent trends are becoming the heart and soul of electrical manufacturing industries. Due to the industry requirement of increasing the strength of these alloys and importance of production of deformed free grains from recrystallisation the present research work aims to suggest a balance between the phenomena of recrystallisation and precipitation in Cu-Cr alloys.

3 METHODOLOGY AND EXPERIMENTATION

3.1 Solutionizing (Solution Heat Treatment)

It is the process of heating a metal alloy to form a homogeneous solid solution. The process can be used on various alloys such as Aluminum and magnesium to refine the grain structure of the alloy and strengthen the metal. The sample is solutionized out at 1000°C for one hour. This is a process in which alloy is heated to a particular temperature and maintained at this temperature so that a particular constituent can enter the solid solution. The aim of this work is to make a solid solution of copper and chromium and then cool down the solution so that precipitation can take place. The solution heat treatment was quite crucial for studying the interaction of recrystallisation with precipitation as precipitation will take place in the solid solution only.

3.2 Annealing

Annealing is a heat treatment process to reduce the hardness of a given object and to remove residual stress from it. The process mainly takes place in three stages- recovery, recrystallization and grain growth. Recovery is the process of movement of low angle grain boundary while recrystallization is the movement of high angle grain boundary. Grain growth mainly takes place in two ways normal grain growth and abnormal grain growth. Abnormal grain growth is also known as secondary recrystallization.

Muffle Furnace: The Muffle Furnace consists of several heating coils which are heated by electric supply and the coils are never in contact with the workpiece and the temperature of the heating chamber is raised to the desired temperature by the action of the heating coils. The furnace is completely electronically controlled. They are mainly used in laboratories as a means to create very high temperature atmospheres. In this work the furnace is used for heat treatment of the alloys at different temperatures for varying period of time.

Figure 1: Muffle Furnace

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

3.3 Polishing of specimen

Polishing is a finishing processes for smoothening the workpiece surface using an abrasive and a work wheel. Actually, polishing includes a set of processes that use a polishing wheel which is attached to abrasive papers and clothes of various grit size, which removes several oxidized impurities deposited on the surface and thus a polished surface with almost mirror like finish is obtained. But sometimes, the polished mirror finish can create a misconception as even in mirror like finish, some impurities may be deposited on the surface. Due to this the proper polishing steps and procedures were followed during the polishing of the specimen.

Using different emery paper (grit size: 600, 800 and 2000) and specimen polishing machine the specimen is polished to get surface finish and other oxidized and other surface impurities are removed. Later the specimen is to be treated with diamond paste with hydraulic oil and polished by polishing cloth. Further the specimen is polished with alumina powder along with water to obtain the mirror like finish at the surface of the specimen.

Figure 2: Specimen polishing machine

Figure 3: Mirror Finished polished specimen

3.4 Rolling

Rolling is the process of decreasing the thickness of the workpiece by the use of cylindrical rolls. A specimen of thickness 5mm with same composition is cold rolled to half of its thickness. The material is rolled using a Two high roll to obtain desired thickness in 4 to 6 passes. The portion of the sample with fifty percent reduction is used to study the microstructure.

Figure 4: Two high roll mill

3.5 Etching of specimen

Etching is the process of using a mixture of acids and alkaline solutions to clean the surface of the workpiece to provide the mirror finish to visualize the microstructure of the sample within a microscope. The part of the workpiece from where metal is to be removed is brought in contact with a strong corrosive chemical called etchant. The workpiece material is immersed inside the etchant solution to achieve the mirror finish.

Etchant Composition: 20 ml NH_4OH (Ammonium Hydroxide) $FeCl_3$ (Ferric Chloride) 1g 20ml H_2O_2 (Hydrogen Peroxide) and 20ml of Distilled water

3.6 Study of microstructure

After etching, the specimen is observed in optical metallurgical microscope under several magnifications and the microstructure to be studied is obtained. For studying the minute details of the microstructure, first samples were studied through the optical microscope followed by detailed study of the samples in scanning electron

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

microscope. Under electron microscope samples were studied in secondary electron mode, backscattered electron mode and electron dispersive spectroscopy mode.

4 RESULTS AND DISCUSSION

4.1 Results of Optical Microscope and SEM

As expected due to the process of casting the microstructure of As-cast structure shows the dendrites with heterogenous distribution of Chromium particles in it. The black spots in the below As-cast microstructure represents the chromium particles.

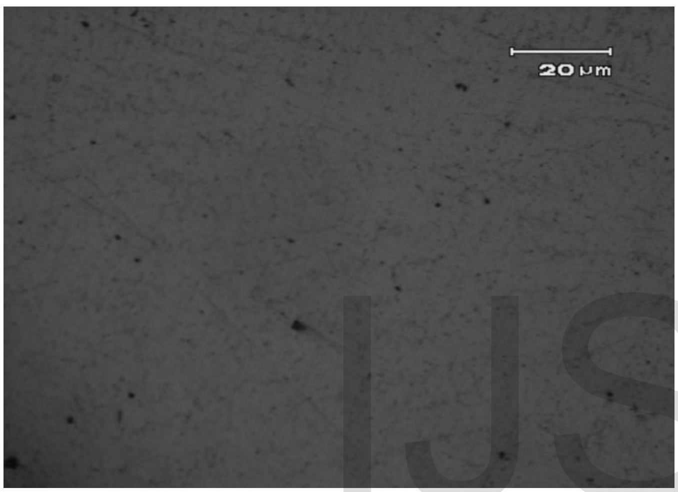


Figure 5: Microstructure of As – Cast Cu – Cr Alloy

After the cold rolling process and reducing the thickness of the specimen by 50%, the deformation bands can be seen quite prominently in the microstructure. These deformation bands indicate the growth of deformation matrix in the Cu-Cr alloy at microstructure level. But after the presence of deformation band also a clear heterogenous distribution of chromium particles can be seen in the deformed matrix as black spots.

Actually, in rolling 3 axes are present. These 3 axes, includes the rolling axis, short transverse axis and the long transverse axis. The rolling axis is in the direction of feed of specimen to the rolling mills, generally it is in horizontal direction. The short transverse axis is in the direction perpendicular to the rolling axis, generally it is in vertical direction. The long transverse axis is mutually perpendicular to both the rolling and normal axis. Due to non-random distribution of orientation in a polycrystalline array the transverse section of rolled samples are studied here.

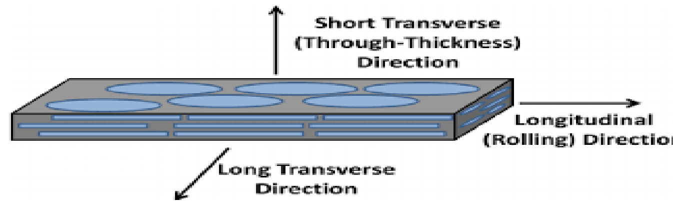


Figure 6: Different Rolling Axes

The coarsened grains of the As-cast structure become elongated. Due to the plastic deformation in case of cold rolling the dislocations pile up and strength goes up which was also supported by the increased hardness (HRB) values.

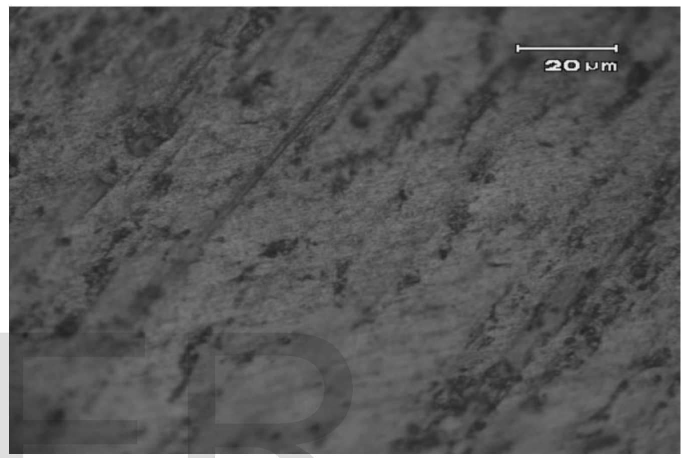


Figure 7: Microstructure of Cold rolled As- Cast Cu – Cr Alloy

After heat treating the cold rolled samples by process of annealing for varying time periods, several microstructures were recorded, and results were concluded by the detailed study of microstructure images. After annealing the cold rolled sample for half an hour, now also prominent deformation bands can be seen. In the annealing process of 0.5 hours there is absence of strain free grains and by this we can conclude that recrystallisation has not taken place after 0.5 hours of annealing of cold rolled non solutionized sample.

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

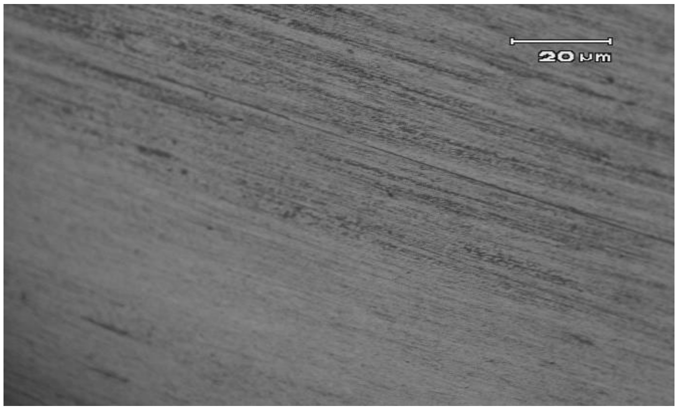


Figure 8: 0.5 hour non-solutionized cold - rolled annealed

In the cold rolled sample which was annealed for a time period of one hour along with prominent deformation bands, strain free grains can also be seen at some points. Thus, the microstructure images of 1 hour annealed cold rolled samples indicates that recrystallisation has started.

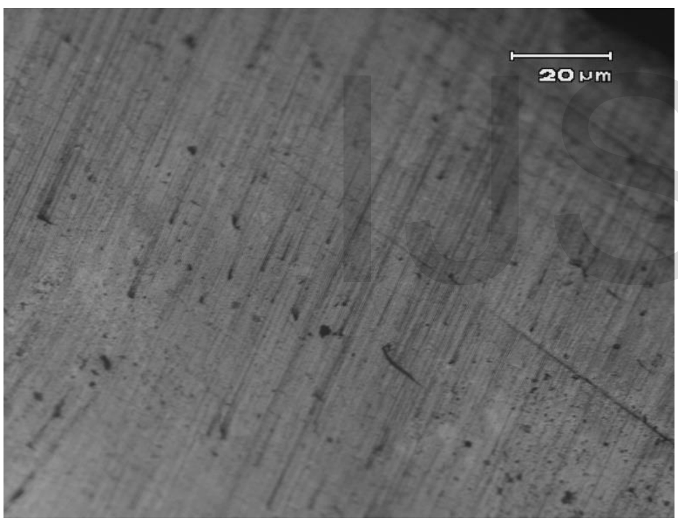


Figure 9: 1 hour non-solutionized cold - rolled annealed

After annealing the cold rolled sample for a period of 1.5 hours also deformation bands can be seen in the microstructure. Along with few deformation bands new strain free grains can also be seen which indicates that recrystallisation has taken place.

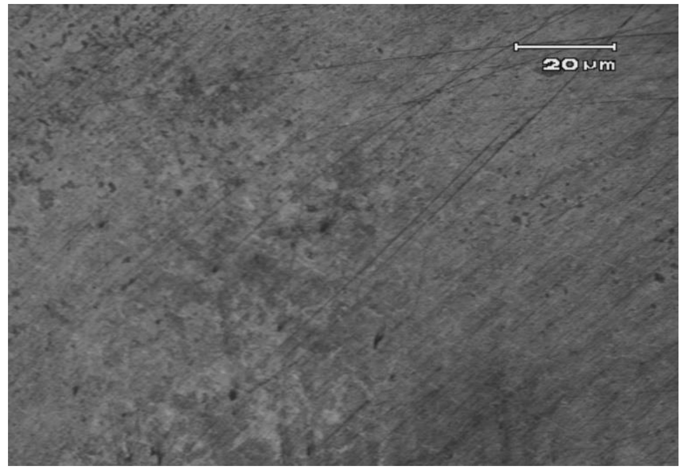


Figure 10: 1.5 hour non-solutionized cold - rolled annealed

After annealing the samples for two hours deformation bands can be seen very rarely in the microstructure. The absence of deformation bands indicate that new grains have been formed and the recrystallisation has taken place. But the rare presence of deformation bands in microstructure also indicates that recrystallisation has not been completed and the structure is not yet fully recrystallized.

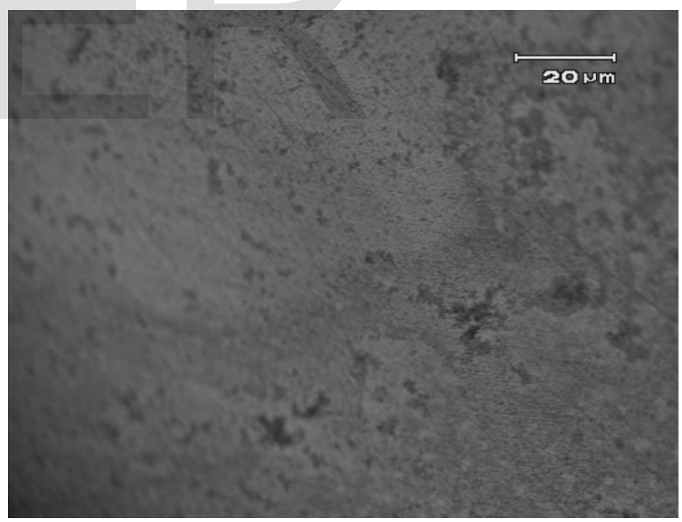


Figure 11: 2 hour non-solutionized cold - rolled annealed

When we annealed the samples for a period of 6 hours no deformation bands are present in the microstructure. Also several strain free grains can be seen at different positions in the images of 6 hours annealed cold rolled microstructure. The absence of deformation bands and presence of new strain free grains clearly indicates that complete recrystallisation has taken place in these samples.

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

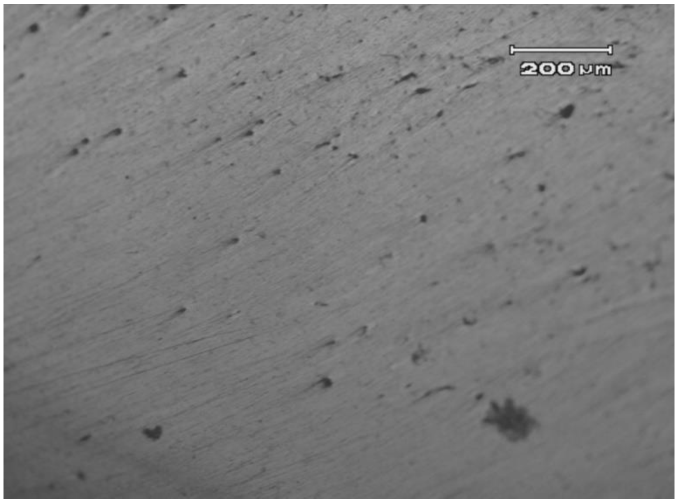


Figure 12: 6 hour non-solutionized cold - rolled annealed

Several theories of nucleation support our findings. Some of the most prominent nucleation theory includes

The Classical Fluctuation Theory: According to this the nucleation may be homogenous as well as heterogenous phenomena. This theory suggests that nucleation generally starts at grain boundaries and areas of defects.

The Growth of Polygonised Sub-grain: According to this theory of nucleation the sub-grains in the deformation matrix achieves an increased size and a larger mis-orientation by coalescence of two or more sub grains.

Strain Induced Boundary Migration(SIBM): This is theory of nucleation which is closely associated with our project and concludes various observations during the experimentation of our project. According to this a sub grain of one grain adjacent to a already existing grain having high angle grain boundary, grows by migration of that boundary into the neighboring grain.

Due to the presence of grains with high angle grain boundaries, SIBM justifies the growth of new grains which facilitated the process of recrystallisation in the non solutionized samples, and thus the microstructure after 6 hours of annealing are deformation free and completely recrystallized.

Now to study the interaction of recrystallisation and precipitation on each other a solid sample was prepared by solution heat treatment process, in which the Cu-Cr alloy samples were heated to 1000 degree centigrade and kept at this temperature for a hour. The Solutionizing of sample was done to facilitate the process of precipitation. After solution heat treatment the process of cold rolling followed by annealing was done for varying time periods.

In the solutionized cold rolled sample after annealing for a period of half an hour prominent deformation bands can be seen which indicates that recrystallisation has not taken place in this sample. But due to very less time period of annealing nothing can be commented on the formation of precipitates as the same prominent deformation bands all over the microstructure can be seen in non solutionized sample also.

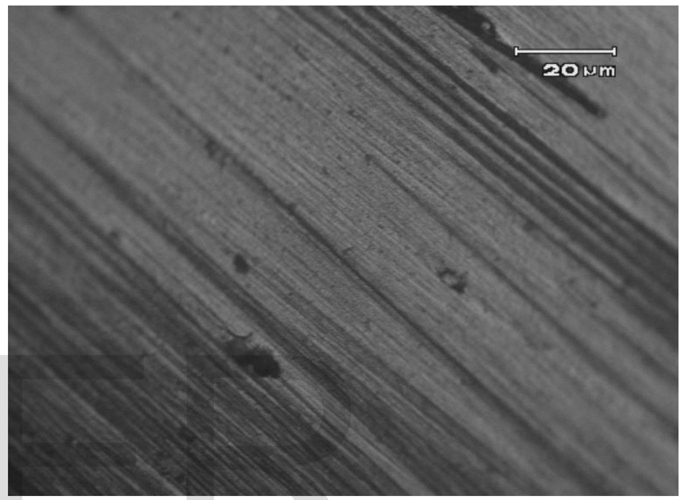


Figure 13: 0.5 hour solutionized cold - rolled annealed

In the microstructure of the solutionized sample after annealing for one hour, now also the deformation bands are quite prominent and can be seen all over the microstructure image. When compared to the non solutionized counterpart, in which new strain free grains can be seen along with the deformation bands, it seems that some precipitates of Cr rich particles have been formed and these precipitates are inhibiting the process of recrystallisation and so recrystallisation has not started after a hour of annealing process also.

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

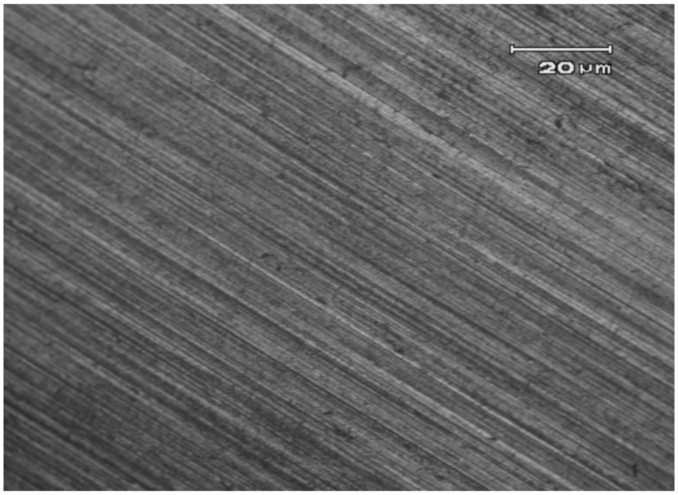


Figure 14: 1 hour solutionized cold - rolled annealed

In the solutionized cold rolled sample after annealing for 1.5 hours also, the deformation bands are present quite all over the microstructure with very few strain free grains. When compared to their non solutionized counterpart, which showed very few deformation bands and many new strain free grain regions, we can easily predict the formation of Cr rich precipitates and inhibition of recrystallisation by these precipitates.

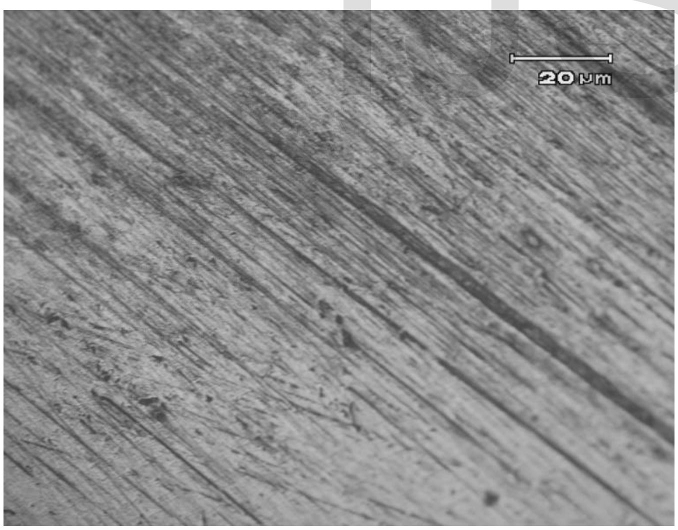


Figure 15: 1.5 hour solutionized cold - rolled annealed

Now the presence of deformation bands after 2 hours of annealing also helps us understand that Cr rich precipitates has been formed at the grain boundary regions. These precipitates thus inhibit the growth of boundary of the sub grain into boundaries of another pre-existing high angle grains. Thus, the strain induced boundary migration has been stopped by the formation of new precipitates. Also due to formation of precipitates the hardness of the specimen is expected to be increased which are supported by the high HRB reading regarding the specimen.

Figure 16: 2 hour solutionized cold - rolled annealed

In the solutionized cold rolled samples after annealing for 6 hours some deformation bands have been disappeared and they have been replaced by new strain free grains at some places. This clearly indicates that after 6 hours of annealing some precipitates have been dissolved in the solid solution of Cu-Cr alloy due to the increased solubility. The solubility of the solid solution has been increased by the prolonged annealing for 6 hours. After dissolution of precipitates in solution, the boundary of the sub grains has migrated and thus recrystallisation has been started at these positions of the microstructure.

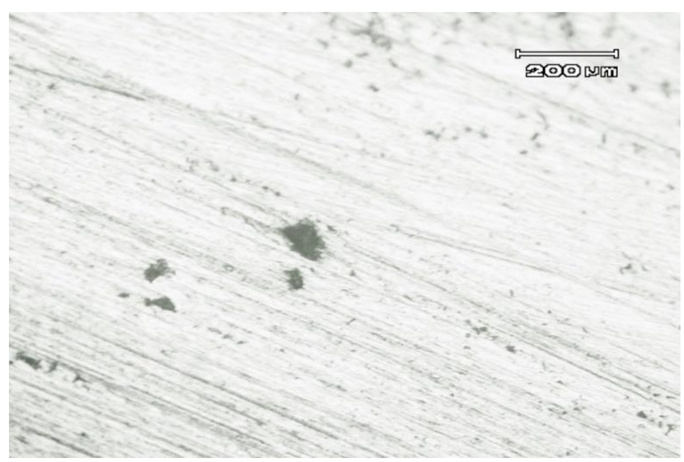


Figure 17: 6 hour solutionized cold - rolled annealed

After analyzing the optical microscope images, SEM images were also analyzed to cross check the results and findings from the optical microscope. In 0.5 hours here also

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

after annealing the cold rolled sample for half an hour, prominent deformation bands can be seen. There is no sign of new strain free grains and by this we can conclude that recrystallisation has not taken place.

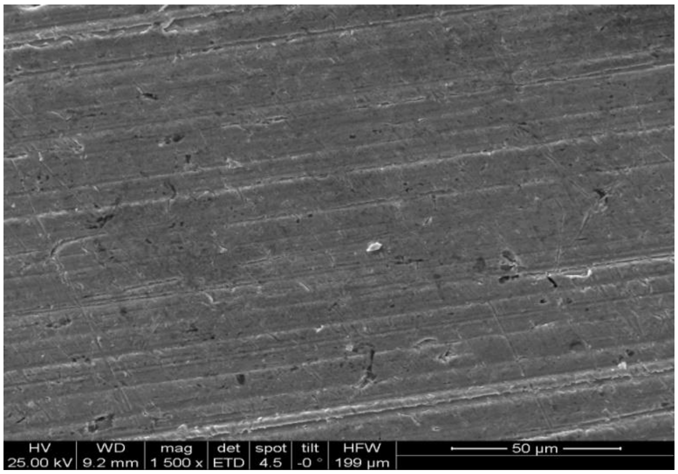


Figure 18: 0.5 hour Non- solutionized cold - rolled annealed (SEM)

In SEM images related to non solutionized samples which were annealed for a hour, along with prominent deformation bands there has been presence of strain free grains at some points. Thus the SEM microstructure images of 1 hour annealed cold rolled samples indicates that recrystallisation has started.

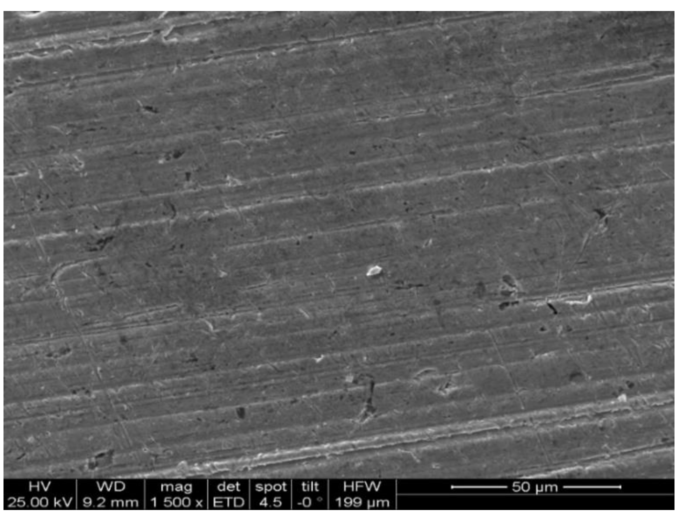


Figure 19: 1 hour Non- solutionized cold - rolled annealed (SEM)

In SEM images also, after annealing the cold rolled sample for a period of 1.5 hours, deformation bands can be seen in the microstructure. Along with few deformation bands new strain free grains can also be seen which indicates that partial recrystallisation has taken place.

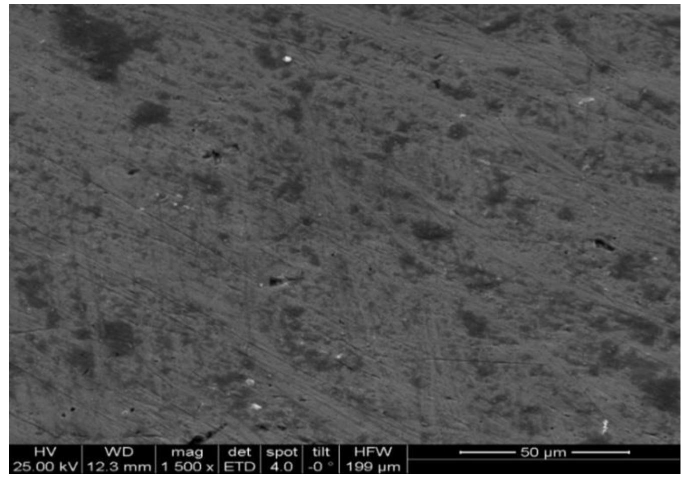


Figure 20: 1.5 hour Non- solutionized cold - rolled annealed (SEM)

In SEM images pertaining to non solutionized cold rolled sample annealed for 2 hours, deformation bands can be seen very rarely in the microstructure. The absence of deformation bands and presence of strain free grains indicate that almost complete recrystallisation has taken place.

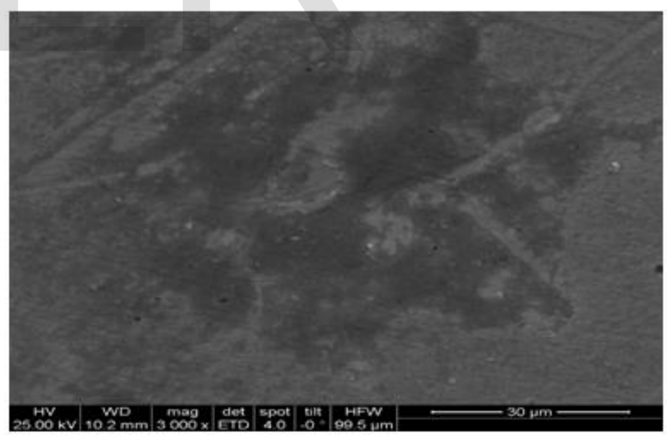


Figure 21: 2 hour Non- solutionized cold - rolled annealed (SEM)

In SEM images pertaining to solutionized sample which were cold rolled and then annealed for 0.5 hours, prominent deformation bands can be seen which indicates that recrystallisation has not taken place in this sample and nothing can be commented on the formation of precipitates on these samples.

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

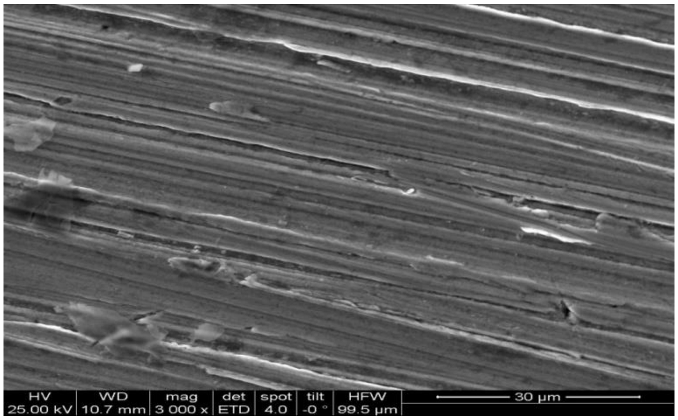


Figure 22: 0.5 hour solutionized cold - rolled annealed (SEM)

The SEM images related to solutionized sample which was annealed for a period of an hour , the deformation bands are quite prominent and can be seen all over the microstructure image. When compared to the non solutionized counterpart, in which new strain free grains can be seen along with the deformation bands, the SEM images indicates the formation of precipitates in the microstructure.

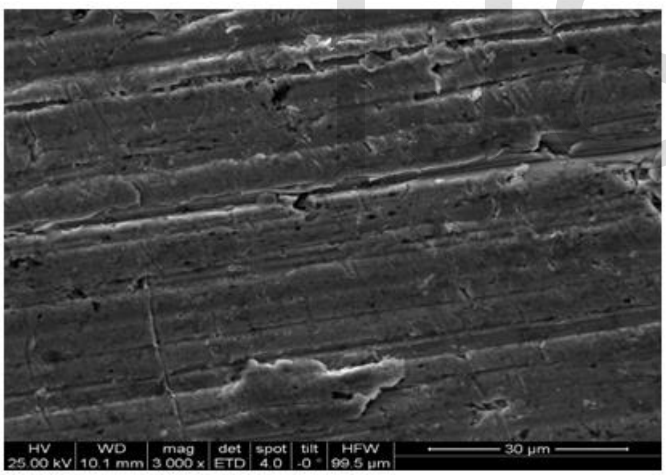


Figure 23: 1 hour solutionized cold - rolled annealed (SEM)

In the SEM images related to solutionized cold rolled sample annealed for a period of 1.5 hours the deformation bands are present quite all over the microstructure with very few strain free grain areas. Thus with SEM images also we can easily predict the formation of Cr rich precipitates and inhibition of recrystallisation by these precipitates.

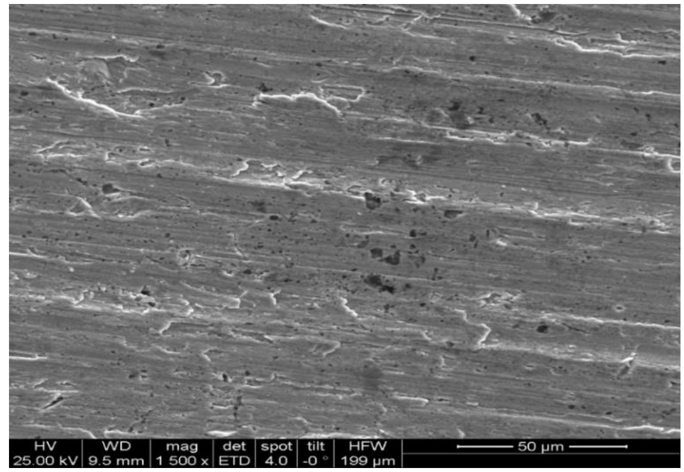


Figure 24: 1.5 hour solutionized cold - rolled annealed (SEM)

The SEM images related to solutionized cold rolled samples annealed for 2 hours, helps us understand that Cr rich precipitates has been formed at the grain boundary regions. These precipitates thus inhibit the growth of boundary of the sub grain into boundaries of another pre existing high angle grains and thus recrystallisation has been inhibited by precipitation.

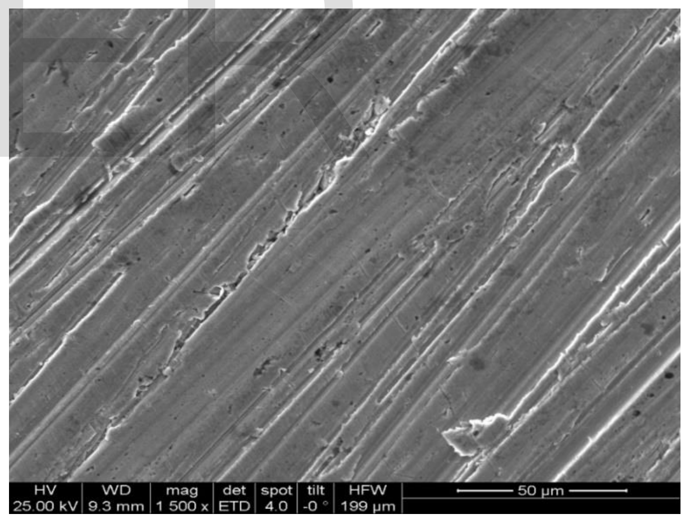
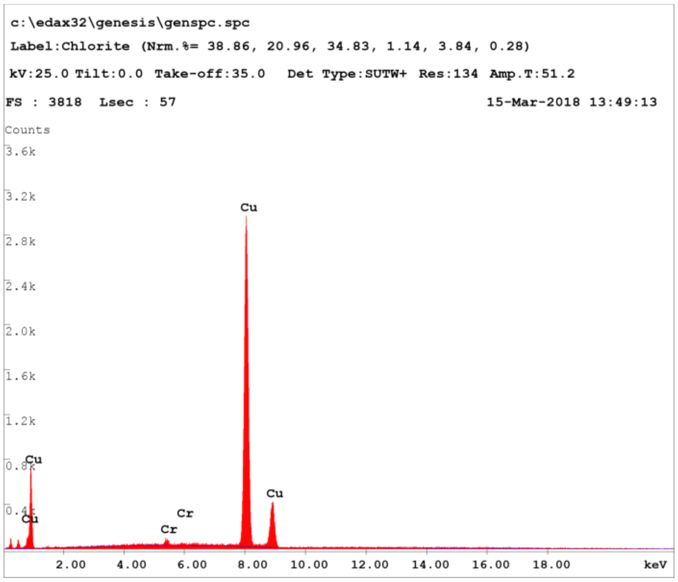


Figure 25: 2 hour solutionized cold - rolled annealed (SEM)

4.2 Results of Energy Dispersive Spectroscopy (EDS)

4.2.1 EDS Results for cold rolled annealed for 0.5 hours

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

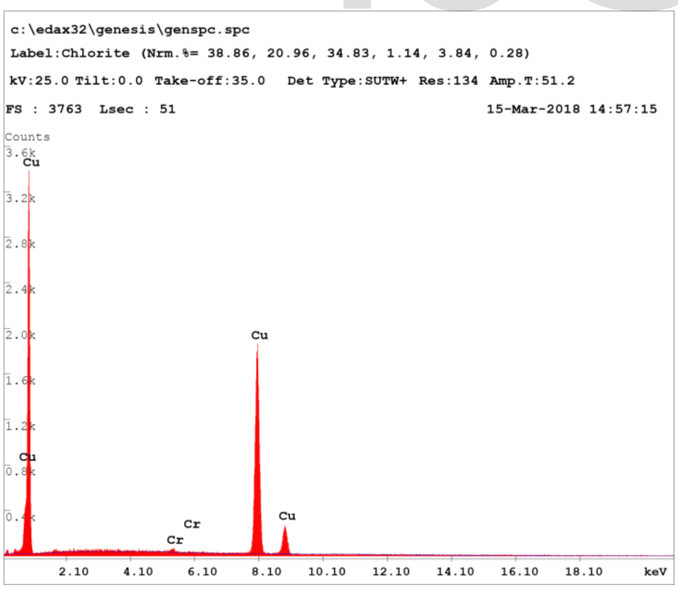


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.78	0.95	0.0085	1.0226	0.9544	1.1289
CuK	99.22	99.05	0.9911	0.9998	0.9990	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	11.13	7.92	6.18	1.40
CuK	656.03	6.01	0.52	109.11

4.2.2 EDS Results for cold rolled annealed for 1 hours

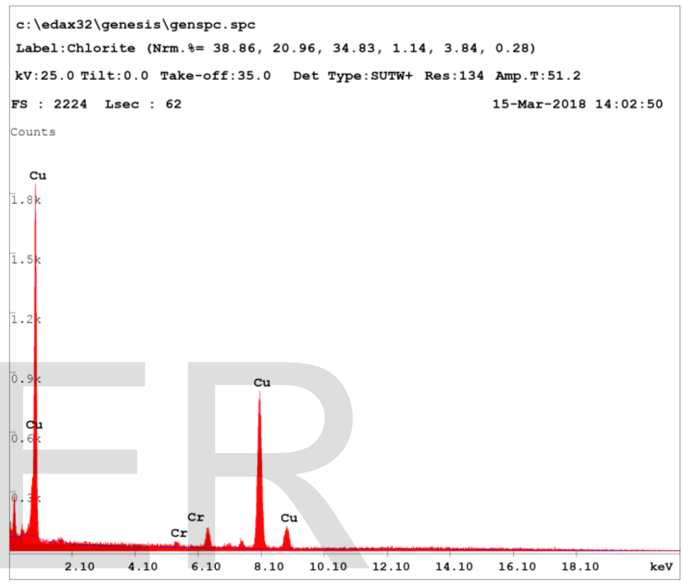


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.69	0.85	0.0077	1.0226	0.9544	1.1292
CuK	99.31	99.15	0.9920	0.9998	0.9991	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	6.65	9.03	10.41	0.74
CuK	437.44	5.89	0.67	74.23

4.2.3 EDS Results for cold rolled annealed for 1.5 hours



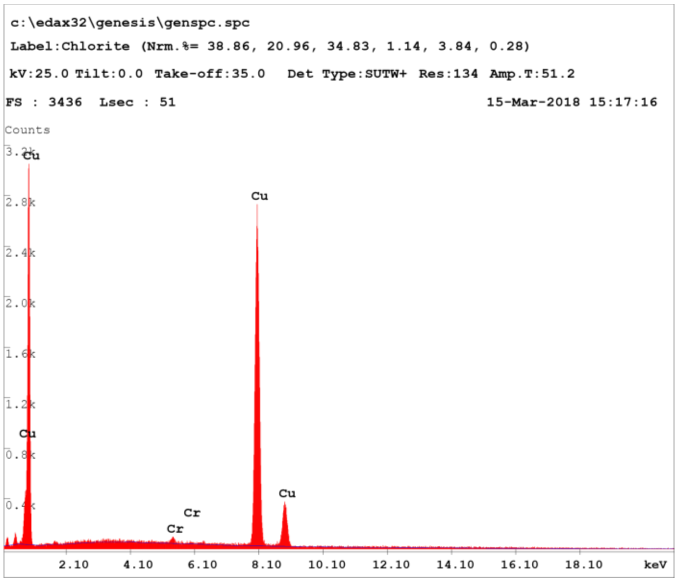
EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	1.38	1.69	0.0152	1.0224	0.9547	1.1271
CuK	98.62	98.31	0.9840	0.9996	0.9982	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	4.97	4.49	9.51	1.11
CuK	162.97	3.14	1.01	51.88

4.2.4 EDS Results for cold rolled annealed for 2 hours

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

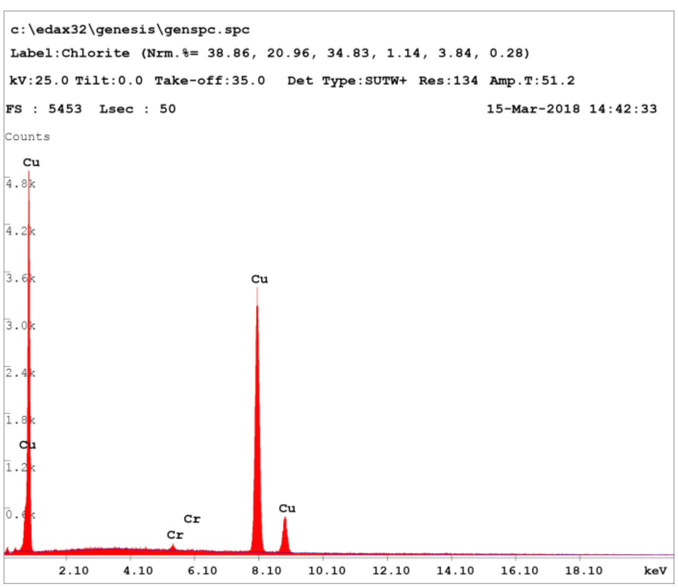


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.78	0.95	0.0086	1.0226	0.9544	1.1289
CuK	99.22	99.05	0.9910	0.9998	0.9990	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	11.09	12.15	7.49	0.91
CuK	650.85	7.58	0.55	85.91

4.2.5 EDS Results for solutionized cold rolled annealed for 0.5 hours

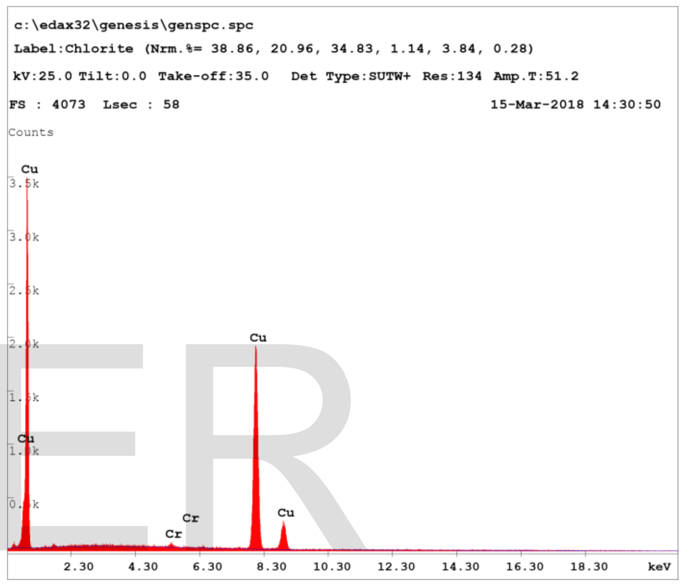


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.79	0.97	0.0088	1.0226	0.9544	1.1289
CuK	99.21	99.03	0.9908	0.9998	0.9990	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	14.32	16.68	6.76	0.86
CuK	822.94	11.63	0.50	70.76

4.2.6 EDS Results for solutionized cold rolled annealed for 1 hour



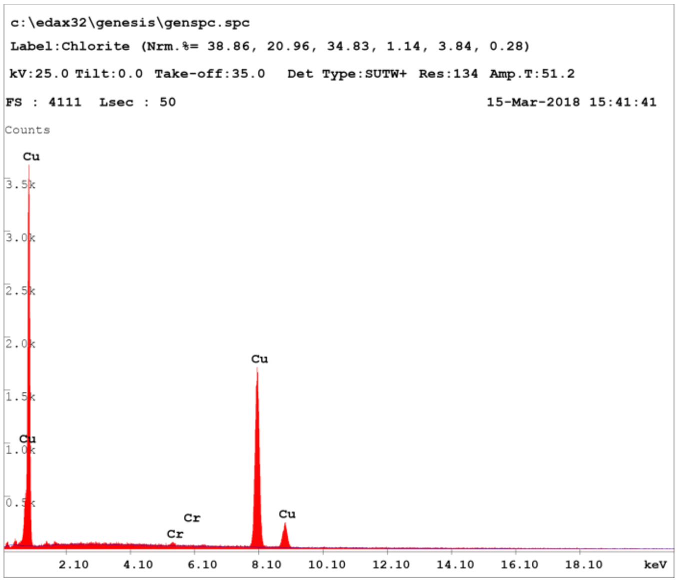
EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.78	0.95	0.0086	1.0226	0.9544	1.1289
CuK	99.22	99.05	0.9910	0.9998	0.9990	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	7.19	8.49	8.95	0.85
CuK	420.34	4.78	0.65	87.98

4.2.7 EDS Results for solutionized cold rolled annealed for 1.5 hour

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

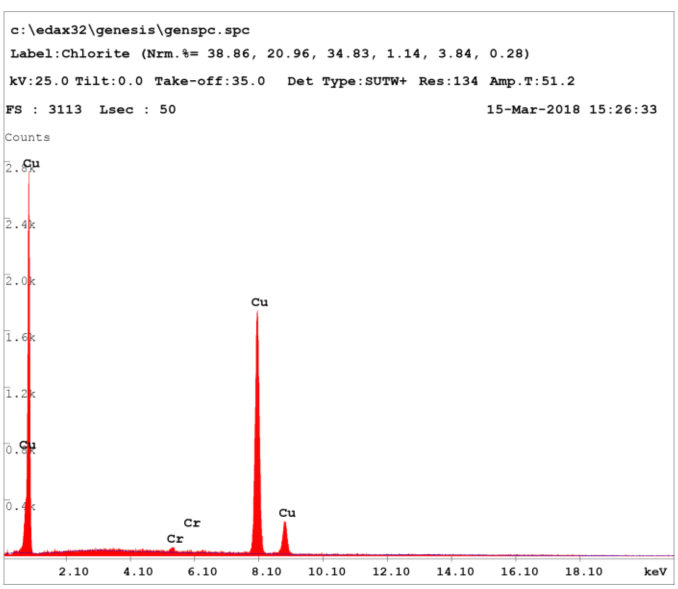


EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.75	0.91	0.0083	1.0226	0.9544	1.1290
CuK	99.25	99.09	0.9914	0.9998	0.9990	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	7.07	8.54	9.81	0.83
CuK	430.82	5.56	0.69	77.56

4.2.8 EDS Results for solutionized cold rolled annealed for 2 hours



EDAX ZAF Quantification (Standardless)
Element Normalized
SEC Table : User c:\edax32\eds\genuser.sec

Element	Wt %	At %	K-Ratio	Z	A	F
CrK	0.83	1.02	0.0092	1.0226	0.9545	1.1288
CuK	99.17	98.98	0.9904	0.9998	0.9989	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/B
CrK	8.05	7.42	8.33	1.08
CuK	441.08	5.22	0.67	84.50

The Energy Dispersive Spectroscopy of all the samples were done to check the weight percentage of both copper as well as the chromium in the Cu-Cr alloy. The main purpose of the EDS study was to see whether after the solution heat treatment of the samples, the Cr distribution in the alloy is same or not. As the solutionized annealed specimens for varying time period were from the same solution heat treated sample so the EDS results can verify the homogeneity of the samples. The EDS results indicated the weight percentage of chromium in different non solutionized sample as 0.78, 0.69, 1.38 and 0.78 respectively. These indicates the heterogenous distribution of chromium in non solutionized sample. The EDS results for solutionized samples were 0.79, 0.78, 0.75 and 0.80. These values indicate that the chromium atoms were homogenously distributed in solutionized samples and thus these specimens have developed solid solution which is the most primary condition for the phenomena of precipitation.

As-Cast	As-Cast Rolled	As-cast Rolled Annealed (1.5hr)	As-Cast Solutionized Rolled Annealed (1.5hr)	As-cast Rolled Annealed (6hr)	As-Cast Solutionized Rolled Annealed (6hr)
51	59	21	33	16	32
59	65	32	68	38	39
52	58	52	63	22	41
49	65	58	74	21	38

Table 1: Hardness values in terms of HRB

CONCLUSIONS

A comprehensive analysis of the results and several hardness data obtained during this experimentation work led to the following conclusion. The hardness of As-cast structure increases after cold rolling and decreases after annealing for a varying time period. But, in case of solutionization, the hardness is increased as compared to non solutionized counterpart due to formation of precipitates. Due to formation of precipitates strain induced boundary migration is inhibited and recrystallisation is

International Journal of Scientific & Engineering Research Volume 12, Issue 8, Aug-2021
ISSN 2229-5518

hindered by precipitates. After annealing for 6 hours, some of the Cr precipitates gets dissolved in solid solution and thus conductivity is expected to increase, as after dissolution of Cr precipitates in solid solution there is comparatively less hinderance to the conducting electrons.

REFERENCES

[1] P. Liu, B.X. Kang, X.G. Kao, J.L. Huang, H.C. Gu "Strengthening Mechanisms in a rapidly solidified and aged Cu-Cr alloy", 2000, Vol-35, Issue 7, pp 1691-1694

[2] Milan Bizjak, Blaz Karpe, Gregor Jaksa, Janez Kovac "Surface precipitation of chromium in rapidly solidified Cu-Cr alloys", 2013, Vol-277, 83-87.

[3] Seyyed Mohammd Hossein Hejazi, Fatameh Majidi, Gholam Hossein Akbari "A Cu-Cr alloy with nano and microscale Cr particles produced in a water-cooled copper mold", 2010, Vol-17, Issue 5, page 629.

[4] R.D. Doherty, Metal Sci. J. Vo;-8, 1974, 132.

[5] W.G. Burgers, Z. Metallkde. Vol-52, 1961,19.

[6] R.W. Cahn "Recrystallization, Grain Growth and Textures", H. Margolin, ASM, Metals Park, Ohio, 1966, 99.

[7] P. A. Beck and P.R. Sperry, J. Applied Physics, Vol-21, 1950, 150.

[8] J. E. Burke and D. Turnbull, Prog. Metal Physics, Vol-3, 1952, 220.

[9] E. Hornbogen and U. Koster, Recrystallization of metallic materials, 1970, 159.