ISSN: 0974-5823 Vol. 6 (Special Issue, Nov.-Dec. 2021)

*International Journal of Mechanical Engineering*

# Effect of addition of Ni on the Microstructure, Hardness and Tensile Properties of Cu-5Zn alloys

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**Abstract**

In this work we report the development of novel copper based alloy with different nickel and zinc weight percentage. The alloy was developed using casting method and additionally heat treatment was carried out to enhance the mechanical properties. The solution and ageing was carried out at 600°C and 450°C at 2 and 4 hours respectively. The copper alloy prepared under different conditions was subjected to microstructural and compositional analysis using scanning electron microscope and X-ray diffraction. Further, the mechanical attributes such as microhardness and tensile properties were studied by subjecting the copper alloy to mechanical testing as per their respective ASTM standards. It is observed that increasing Ni content and ageing improved the microhardness and strength of alloys. However the elongation was found to be affected due to presence of higher Ni content and $Cu_2NiZn$ precipitates. The tensile fracture analysis was found to ductile mode for low Ni content alloy while for higher Ni content the failure was mixed mode.

**Keywords:** Cu-Zn alloy; Heat treatment; Microstructure; Mechanical properties.

## 1.0 Introduction

Copper and its alloys are most used metallic materials after aluminum and steel either in term of production or consumption. The usage of copper started in the early 8700 B.C. in the form decorative pendants and other items like chisels, water vessels and razors. However after realizing its excellent physical properties such as high electrical (100% IACS) and thermal conductivity (397 W $m^{-1}K^{-1}$) its application rapidly expanded into electrical and heat flux applications. The numerous applications of copper include spark plugs, heat exchangers, power transmission lines, refrigeration tubing, divertor cryopump, busbar systems, conductors, wire systems, electrical windings, electrical contacts, water-cooled baffles, catenary wire for electric railroads and resistance welding electrodes [1,2]. In addition to this, copper is also known for its excellent resistance against corrosion, its highly malleable, and good fatigue resistance. Due to its corrosion resistance property it is employed in making valves, fittings and pipes for carrying water and aqueous fluid. The pure copper generally has copper content of 99.3% and with such chemical composition it has low hardness, low strength but extremely ductile. Even from the processing point of pure copper is very difficult to cast and often prone to porosity related issues, cracking and formation of voids in the interiors of cast part. So in order to overcome the drawbacks pertaining to processing and properties, the pure copper is alloyed with metallic elements such as silicon, zinc, beryllium, nickel, silver, tin, lithium and chromium. Apart from this, opting additional processing techniques like grain refinement, precipitation hardening and cold working helps copper to attain high strength. However, the issue with alloying or subjecting to secondary processing conditions often leads to drop in the conductivity values [3,4]. Take for instance, Abbas et al [5] reported drop in the electrical conductivity values when Fe content in copper was increased from 10 at% to 50 at%. Formation of cylindrical voids and smaller grains led to decrease in conductivity values. On the contrary authors found that heat treatment of these alloys enhancement in the electrical conductivity due to increase in grain size. In case of copper alloys the main challenge is to develop compositions that possess both high strength and ductility without affecting electrical conductivity significantly.

Various alloying elements in either low or high weight percentage are added to copper to enhance its indentation resistance and strength. Based on the alloying elements the alloy are termed as red brass, yellow brass, semi-red brass, bronze, silicon bronze, nickel-tin bronze, aluminium bronze and copper-nickel alloys. However, out of all the brass is quite popular copper alloy because of its high strength, corrosion resistance, castability and most importantly it is relatively least expensive. The main alloying element of this copper alloy is zinc but in some cases it also contains tin, lead and manganese. The zinc content varies from 2% to 35% and with the increasing zinc content, both strength and ductility are found to increase. However, additional attempts on enhancing strength were also conducted by adding other alloying elements and secondary phases such as ceramic particulates [6-8]. For instance, Adineh et al [9] studied the effect of addition of Al and Si on the microstructure and mechanical attributes of Cu-3Zn alloy. The Al content in the range of 1.89% - 4.72% and Si content from 0.83% to 3.62% was varied. The developed alloys showed increase in Brinell hardness and strength as the Al and Si was increased but out of the two the addition of Al was found to be more beneficial. The enhancement of hardness was attributed to the formation of hexagonal structured β' phase. On the contrary in another work the same authors reported drop in tensile strength values after addition of Mg and Sb to Cu-Zn alloy [10]. However, the hardness was found to increase as the Mg and Si content in the Cu-Zn alloy was increased. The alloy was showed presence of hard phase such as CuZnMg whose hardness found to be in the range of 64-68 HV. Formation of intermetallic compounds rich in copper led to decrease in the tensile strength but helped in enhancing the hardness values. Chen et al [11] studied the effect of alloying elements like Ni and Si on mechanical behavior of Cu-10Zn and Cu-20Zn alloys. The Ni and Si content in both the copper alloys were fixed to 1.5% and 0.34% respectively. The addition of alloying elements led to the formation of intermetallic compounds such as $Ni_2Si$ and $Ni_3Si$. Both hardness and tensile strength of Cu-10Zn and Cu-20Zn alloys was increased and the strengthening was attributed to work hardening, grain boundary strengthening, Orowan strengthening and solution strengthening. In another work, Basori et al [12] reported development of Cu-10Zn with Al as additional alloying element. The hardness and tensile test were carried out as per ASTM E384 and ASTM E8 standards respectively. With the increase in Al content from 1% to 4%, the hardness increased from 68 VHN to 119 VHN. On similar note the tensile strength of Cu-10Zn increased from 167 MPa to 248 MPa for 5.93% Al addition. It is seen that different alloying elements has different effect on the mechanical properties as some tend to enhance the properties while are detrimental to it. In this careful selection of alloying element can result in the enhanced microhardness and strength. Taking a cue from all these works, we report the development of Cu-5Zn alloy with varying Ni content (4% - 12%). The effect of variation is observed in the microstructure, hardness and tensile properties of Cu-5Zn alloy.

## 2.0 Experimentation

Cu-5Zn alloy with Ni addition was prepared via casting technique and for this copper in ingot form (electrolytic grade, 99.95%), Ni in the powder form and Zn metal pieces were used as starting materials. The X-ray diffraction pattern of Ni metal is provided in the Fig. 1 . First the copper ingots were place in the graphite crucible and the temperature of the furnace was set to 1100°C. Once the melting was copper was started, the furnace temperature was further increased to 1500°C and Ni was added to the copper melt. The molten copper with Ni is stirred neatly to ensure that it distributes uniformly with settling and clustering. After ensuring melting of both the metals, slag was removed and hexachlorothane ($C_2Cl_6$) tablets were added to molten mixture of copper and nickel to remove any entrapped gases. Once the cleaning is done the next step was to add zinc and stirred for few minutes to ensure uniform mixing. The molten melt is finally poured into sand mould have rectangular cross-section and allowed to solidify. The as cast Cu-5Zn alloys with different Ni content with their designations is provided in the Table 1. Further, the cast alloy samples were subjected to heat treatment cycles as mentioned below,

i. Cycle 1: Solution treatment at 600°C for 4hours, water quenching to room temperature and ageing at 450°C for about 4 hours.

All, cast, heat treated and aged samples were subjected to X-ray diffraction (Make: ) and scanning electron microscopy (Make: Tescan Vega3) studies. The hardness and tensile test of all samples were carried out as per ASTM E384 and ASTM E8 standards respectively. The photographs of cast and aged tensile samples prepared for tension test is presented in the Fig. 2. The fractured tensile samples were subjected to SEM analysis to analyze the fracture mechanisms.

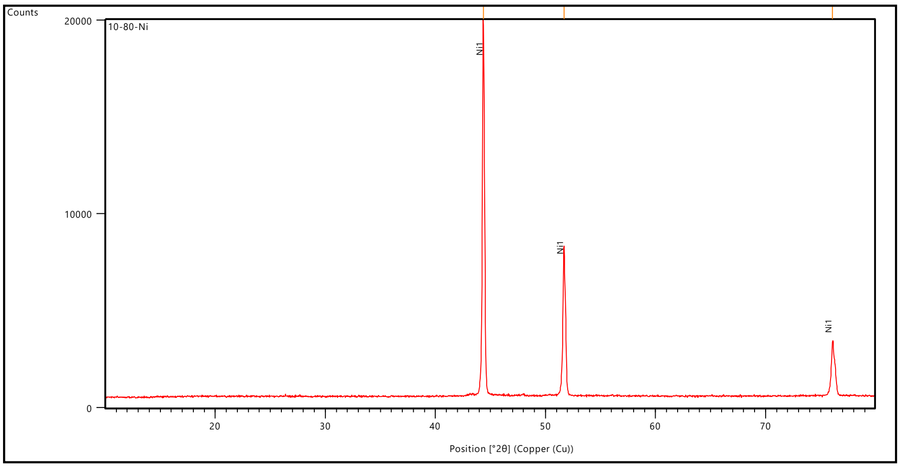



**Fig. 1 X-ray diffraction patterns of as received Ni**

**Table 1.**

| Sample Desgn. | Composition |
|---|---|
| Alloy 1 | Copper + 5% Zn + 4% Ni |
| Alloy 2 | Copper + 5% Zn + 8% Ni |
| Alloy 3 | Copper + 5% Zn + 12% Ni |

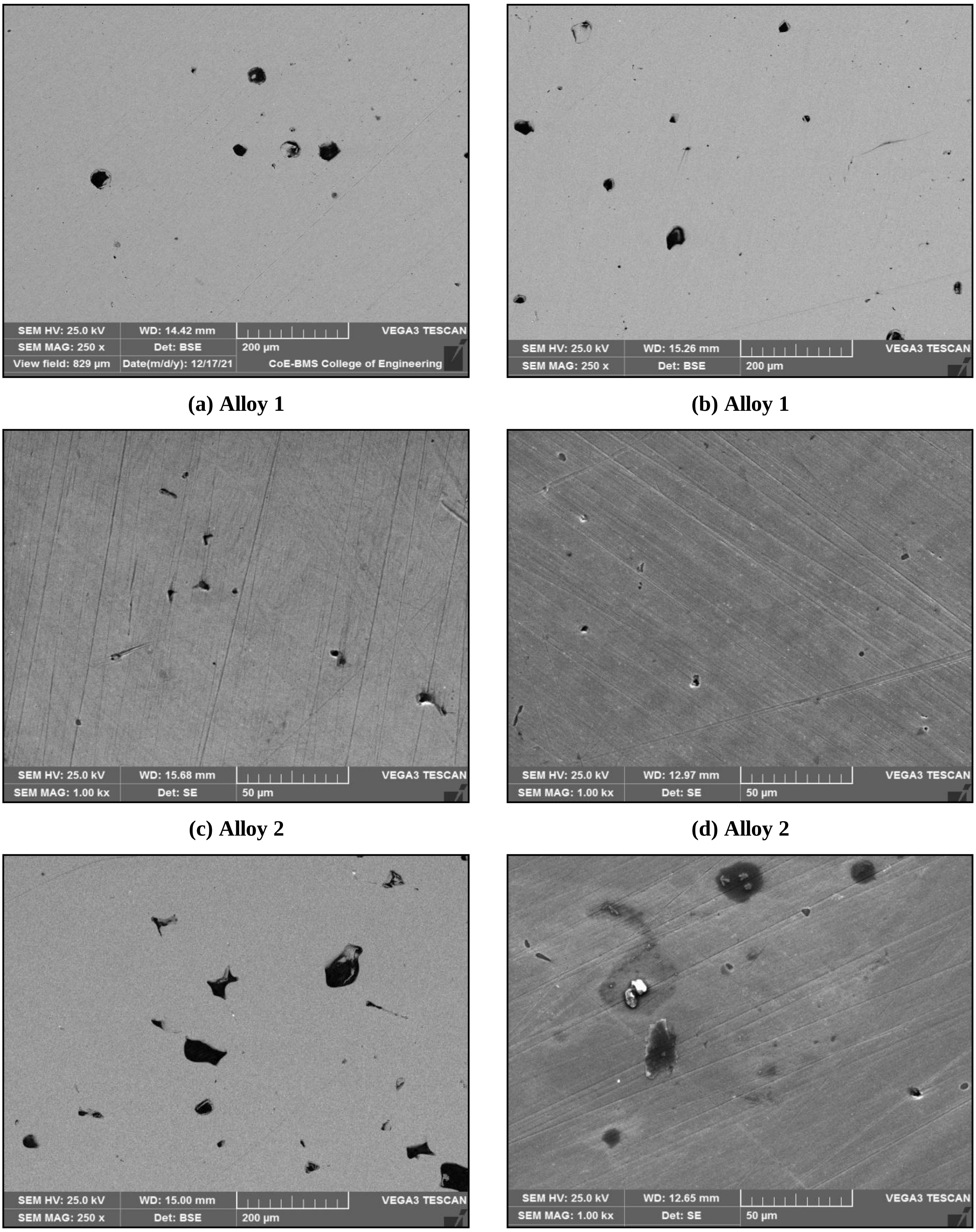
**(a)** **(b)**

**Fig. 2:** Photographs of Alloy 1 in (a) cast and (b) heat treated conditions Sample composition and their respective designations

### 3.0 Results and Discussion

### 3.1 Microstructure

The SEM micrographs depicting the microstructure of as cast and aged samples are shown in the Fig. 3 (a) - (f). Each micrograph presents the effect of alloying element and ageing process on the microstructure of the Cu-5%Zn alloy. As seen in the micrograph, the Alloy 1 which contains about 4%Ni showed typical microstructure comprising of large copper solid solution which is generally called as α-phase (alpha) (see Fig. 3 (a)). However, it is noticed that the β-phase is not as dominant or is rarely seen in this micrograph. Generally in case of Cu with approximately 40%Zn, the zinc rich β-phase is also observed along with α-phase. This zinc rich β-phase is found in between the gaps of primary dendrites of α-phase. If the zinc content in Cu goes beyond 40% then the primary dendrites belong to β-phase and are surrounded by the α-phase. Since the Zn content in present case is just 5%, the formation of zinc rich β-phase is quite minimal and is observed at very few locations surrounding the α-phase. Take for instance, Rotty et al [13] presented the microstructure analysis of Cu-Zn and Cu-Zn-Pb alloys. In both the alloys the Zn content was 42% and 39%, due to which the microstructure showed dual phases, α-phase and β-phase. In case of Cu-Zn-Pb alloy the lead particles were found to be accumulated at the interfaces between α-phase and β-phase. So in comparison with the present work were Zn content is just 5% the micrograph showed dominant copper solid solution or simply known as α-phase. Further, despite of the fact that alloy was developed using casting technique, there were no signs of dendritic structure. The absence of such structure can be attributed to mechanical stirring during casting process which breaks down the dendrites. In addition to this the Ni particles accumulate in the front of solid-liquid interface which leads to constitutional undercooling. The possibility of dendrite arm growth is largely limited by constitutional undercooling created by Ni particles thereby refining the structure by breaking and melting the dendrite arms [14]. On the other hand Alloy 1 after solution treatment and ageing showed no much difference in the microstructure except for small increase in the average grain size (see Fig. 3 (b)). Although tiny black coloured dots were seen in the microstructure indicating formation of precipitates in the alloy. Based on the alloy composition it is quite clear that the precipitates formed after ageing process has composition close to $Cu_2NiZn$. When the Ni content in Cu-5%Zn was increased from 4% to 8%, the microstructure of Alloy 2 showed considerable refinement and decrease in average grain size (See Fig. 3 (c)). The Ni particles are seems to have located at the grain boundaries of α-phase with uniform dispersion all over the alloy. However the microstructure still contained pure α-phase grains with no β-phase or dendritic structure. The absence of dendritic morphology which is quite common feature of sand casting explains that the mechanical stirring and presence of Ni particles has resulted in the formation of equiaxed grains. After ageing the Alloy 2 showed marginal increase in the average grain size while rest of structural features such as presence of pure α-phase grains and absence of dendritic structure was similar to that of cast condition. However as seen for Alloy 1 (Fig. 3 (b)), here the micrograph Fig. 3 (d) showed tiny black spots corresponding to precipitates. Finally when the Ni content was increased from 8% to 12%, the microstructure of Alloy 3 as seen in the Fig. 3 (e) showed considerable grain refinement.




**(a) Alloy 1** **(b) Alloy 1**

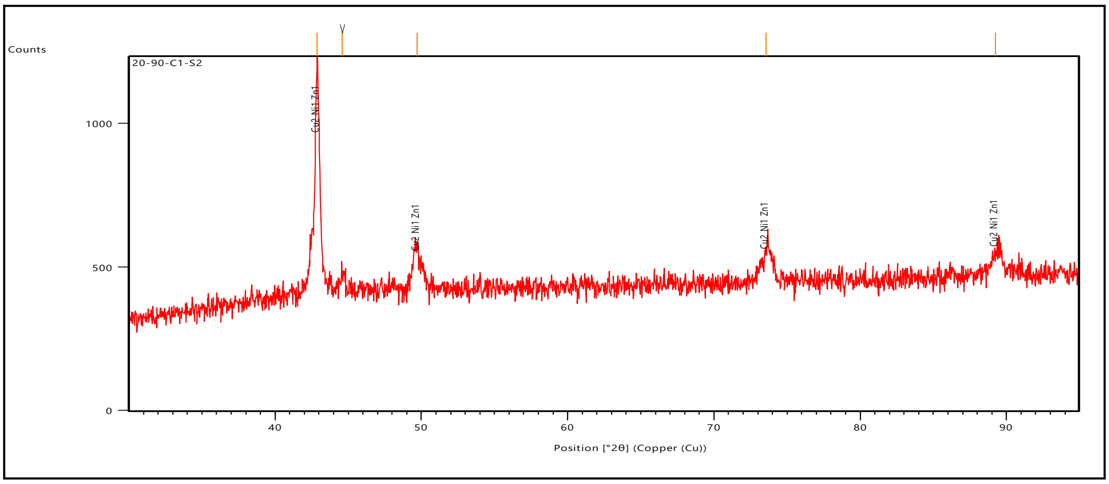
**(c) Alloy 2** **(d) Alloy 2**

**(e) Alloy 3** **(f) Alloy 3**

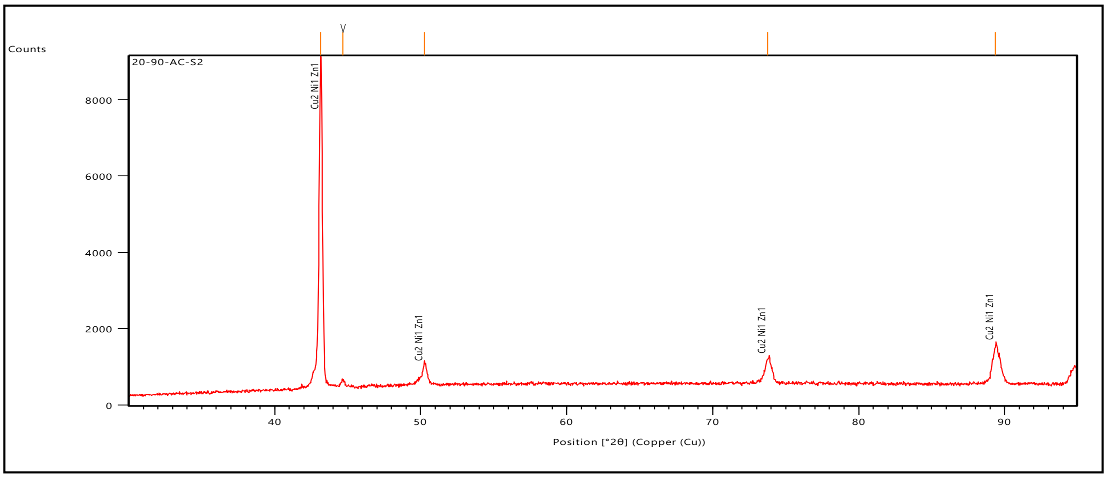
**Fig. 3:** SEM micrographs of (a,c,e) cast and (b,d,f) aged samples (4 hours)

In addition to pure α-phase grain the Ni particles were seemed to be located at the grain boundaries. With the increase in number of Ni particles the constitutional undercooling is more pronounced due to which the amount of dendrite modification in this alloy is significantly higher than that of Alloy 1 and 2. Apart from decrease in the average grain size this alloy showed almost same microstructural features as that of Alloy 1 and 2. However due to presence of high Ni content the dendritic structure modification and grain refinement is more pronounced in this alloy. A similar observation was reported by Alaneme and Umar [15] on their work on Ni modified Cu-Zn-Al alloy. Due to the addition of Ni there was significant modification in the grain structure from sharp elongated grains to granular structure having smaller size. Unlike in this reference the grain structure in the present case was equiaxed in the appearance. The aged Alloy 3 microstructure was same as that of it cast counterpart but difference were marginal increase in average grain size and formation of precipitates. The precipitates are seemed to be higher in number due to higher Ni content when compared to Alloy 1 and 2.

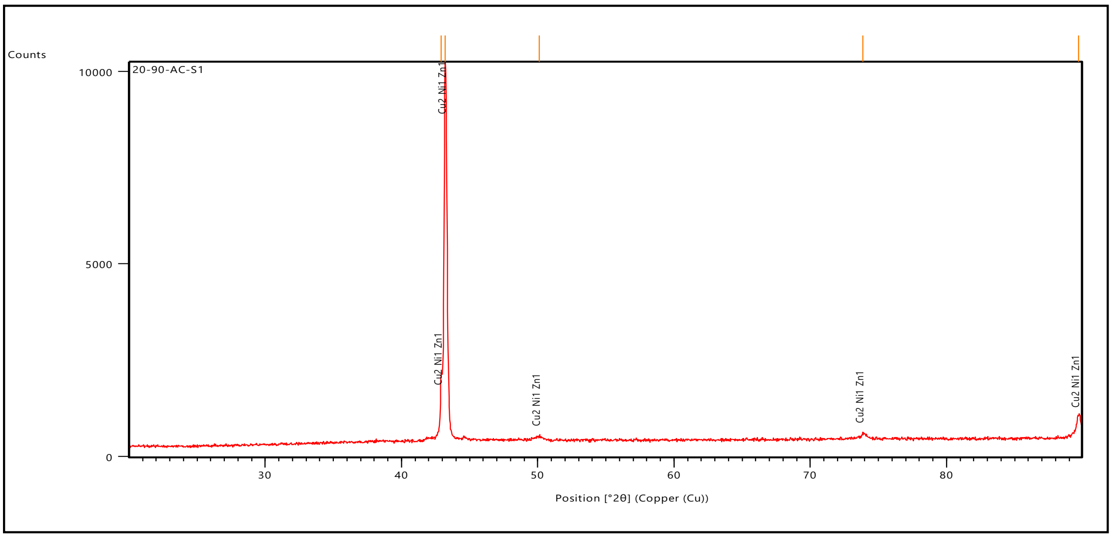
The Cu-5%Zn alloy samples with varying Ni content were subjected to X-ray diffraction analysis to study the phases formed after ageing process. The X-ray diffraction patterns for alloy with 4%, 8% and 12% Ni content is presented in the Fig. 4 (a) – (c). All the patterns taken over the tiny dark spots confirms the presence of precipitates whose composition is equal to $Cu_2NiZn$. The presence of precipitates was found to be more uniform in the matrix because the patterns showed high intensity peaks for $Cu_2NiZn$ phase. Distinct peaks at $2\theta$ = 43°, 49.5°, 73.5° and 89.5° corresponding to $Cu_2NiZn$ phase were observed for all the three alloys. The major difference in these patterns is intensity of the peak and with the increase in Ni content the intensity of $Cu_2NiZn$ phase is also increasing. The high intensity peaks were observed for alloy 2 and 3 (Fig. 4 (b) and (c)) and this is attributed to presence of large number of $Cu_2NiZn$ phase which were segregated from the matrix. However, observing precipitates is quite tedious task as sometimes due to their size, dispersion and density the peak corresponding to them might not be detected. On a similar note Dianez et al [16] observed the $Cu_2NiZn$ phase in TEM but X-ray diffraction pattern showed no peaks corresponding to this phase. Though the precipitates might have observed in TEM but the density was not high enough to be detected in the X-ray diffraction patterns.




**(a) Alloy 1**




**(b) Alloy 2**




**(c) Alloy 3**

**Fig. 4 :** X-ray diffraction patterns of aged Cu-5%Zn alloys with varying Ni content

**3.2 Microhardness**

The microhardness of Cu-5%Zn alloy samples with 4%, 8% and 12% Ni content in both cast and aged conditions is shown in the Fig. 5. Here there are two scenarios, first one is varying Ni content and second one is cast/aged conditions. Let's see the first case where we will see the hardness recorded for varying Ni content for both cast and aged conditions. The microhardness of cast Alloy 1 which contains 4% of Ni was found to be 76.7 HV. Further, with the increasing Ni content of 8% and 12%, the microhardness of cast Alloy 2 and 3 were increased to 80 HV and 85 HV. The alloy with highest Ni content showed highest microhardness and when compared to Alloy 1 and 2, the increase in the microhardness was about 10.8% and 6.3%. Strictly from Ni point of view, the increment in the microhardness can be attributed to modification in structure to mechanical stirring and decrease in grain size. First, the conventional stir casting produces the Cu-Zn alloy with α-phase and β-phases dendrites. The β-phase is usually found in the interdendritic regions of α-phase or α-dendrites are separated by the β-phase regions. The interface between α and β-phase is prime location for formation of casting defects like shrinkage [17]. However in present case, the mechanical stirrer generates high shear rate which easily breaks the dendrites formed in the semi-solid mixture of metals. In addition to this the Ni particles which are added to the copper melt gets accumulated in the front of solid-liquid interface which leads to constitutional undercooling. The dendrite arm growth is largely limited by constitutional undercooling created by Ni particles thereby refine the microstructure by breaking and melting the dendrite arms. Further, presence of Ni at α grain boundaries and its uniform dispersion in the alloy help improving hardness. The Ni tend provide utmost resistance to the plastic deformation when the indentation is being made by the indenter. In addition to this the decrease in grain size was observed when Ni was added to Cu-Zn alloy. The grain refinement causes increase in number of grain boundaries. These grain boundaries act as barrier to the dislocation motion thereby providing resistance against plastic deformation. So from this it is quite clear that higher the Ni content more will be the number of grain boundaries which is turn enhances the hardness by inhibiting the dislocation motion. These observations are well inline those reported by Gao et al [18] on La added brass alloy where La addition led into increase in hardness of brass alloys prepared by squeeze casting. The increase in hardness was attributed to constitutional undercooling led grain refinement process and inhibition to slip of dislocations. From these factors one can obtain optimized casting microstructure with minimal casting related defects there by enhancing the microhardness of Cu-Zn alloy.

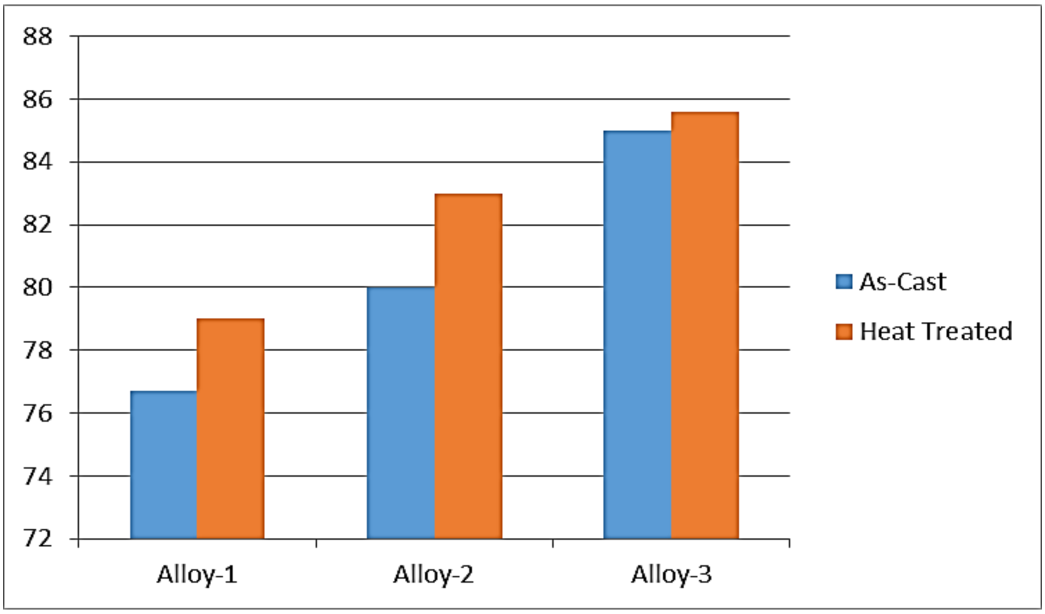



**Fig. 5:** Microhardness of as cast and aged Cu-5%Zn alloys with varying Ni content

Now let's see the microhardness for alloys in two different processing conditions, cast and aged. The microhardness of cast and aged Alloy 1 which contains 4% of Ni was found to be 76.7 HV and 79 HV. The ageing process has improved the hardness of Alloy 1 by ~3% which is quite marginal enhancement. The microhardness of aged Alloy 2 and 3 was found to be 83 HV and 85.8 HV which when compared with their cast counterparts showed about ~3.8% and ~0.9% improvement. Overall, prolong ageing time of 4 hours led to precipitates to grow larger in size due to which the microhardness improved marginally. Out of all, the aged Alloy 2 showed highest increment in microhardness when compared with its cast counterpart but the highest value was recorded for Alloy 3. This is due to the highest Ni particle content in this alloy which when interact with the matrix tend to emit dislocations whose density is quite higher than that of Alloy 1 and 2. With the increase in the dislocation density the distance between the dislocations decreases and in such a case the movement of dislocations is greatly retarded leading to highest enhancement in the microhardness in the Alloy 3. In addition to this the enhancement can also be attributed to formation of $Cu_2NiZn$ precipitates which contribute via same mechanisms, blocking the grain boundary and hindering dislocation motion. Initially the coherent precipitates are formed in the copper matrix which are quite efficient in the pining the dislocations as well as grain boundaries. But as the ageing time duration increases they tend to grow such that the pinning effect is weakened. So the marginal increase is due to the formation of larger precipitates which could be easily sheared by the moving dislocations providing least resistance against indentation. Similar observation of precipitation coarsening was reported by Li et al [19] in their work on Cu-40%Zn-1%Ti alloy. The coarsened $Cu_2TiZn$ precipitates found at the grain boundaries had weak pinning force against grain boundary migration which resulted in poor hardness values.

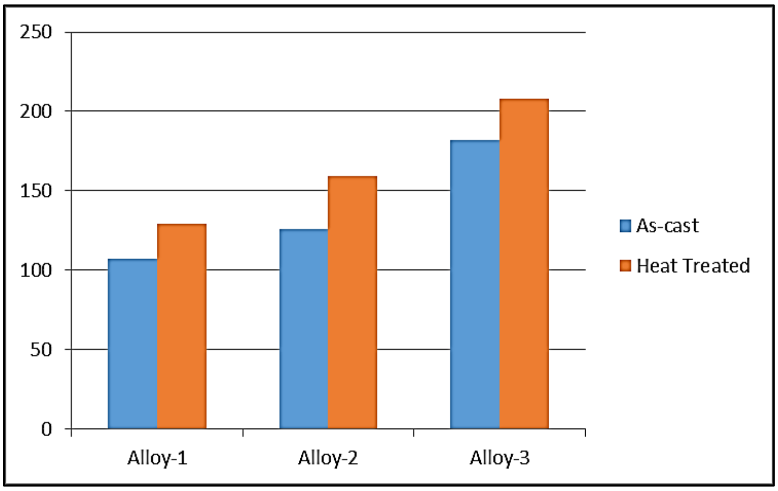
### 3.3 Tensile properties

The tensile properties of Cu-5%Zn alloy samples with 4%, 8% and 12% Ni content in both cast and aged conditions is shown in the Fig. 6 (a) – (c). All the three tensile properties, yield strength, ultimate tensile strength and elongation values were recorded for all alloys and for both cast and aged conditions.

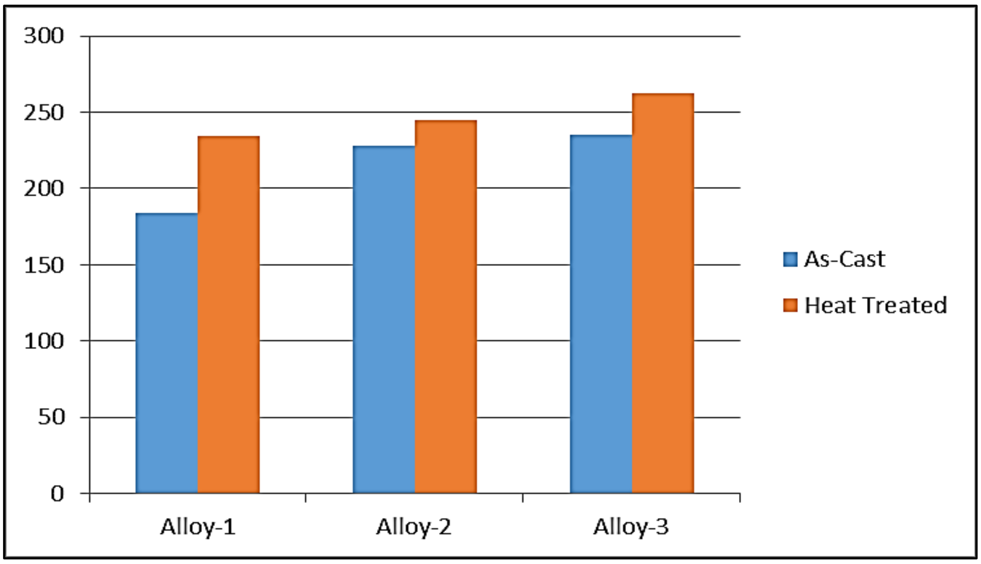
#### *3.3.1 Yield and ultimate tensile strength*

The yield strength of Cu-5%Zn alloy samples with varying Ni content in both cast and aged conditions is shown in Fig. 6 (a). The yield strength of cast Alloy 1 which contains 4% of Ni was found to be 108 MPa. Further, with the increasing Ni content of 8% and 12%, the yield strength of cast Alloy 2 and 3 were increased to 126 MPa and 180 MPa respectively. The alloy with highest Ni content showed highest yield strength and when compared to Alloy 1 and 2, the increase in the yield strength of Alloy 3 was about 66.7% and 42.8%. So strictly from Ni content point of view the yield strength was found to be increasing as Ni content was increased. On the other hand the comparison between cast and aged alloys was done and found that after ageing the yield strength value increased for respective alloys. For instance, the yield strength of aged Alloy 1 which contains 4% of Ni was found to be 129 MPa and when compared with its cast counterpart the increase was about 19.4%. The yield strength of aged Alloy 2 and 3 with 8% and 12% Ni content showed values of 159 MPa and 206 MPa. When compared with cast counterparts the increase in strength was about 26.2% and 14.4% for Alloy 2 and 3 respectively.

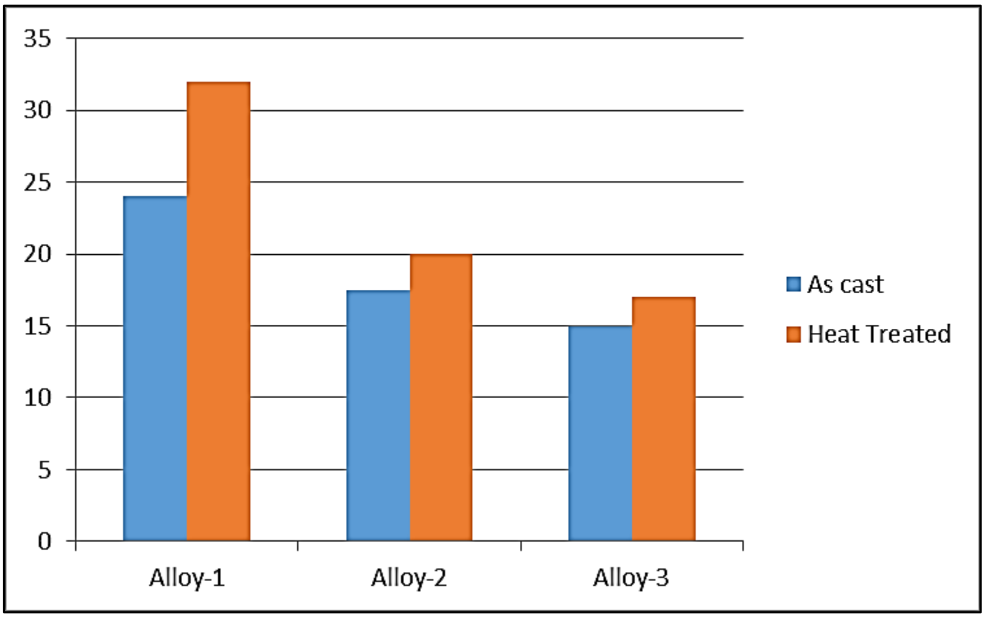
Further, the ultimate tensile strength of Cu-5%Zn alloy samples with varying Ni content in both cast and aged conditions is shown in Fig. 6 (b). As the Ni content increased for 4% to 12%, the ultimate tensile strength was found to increase from 182 MPa to 241 MPa. This implies that increasing Ni content showed increase in the ultimate tensile strength of Cu-5%Zn alloy samples. As seen in the figure the highest strength value was observed for Alloy 3 which showed a value of 241 MPa. When compared with the Alloy 1 and 2, the increase in strength of Alloy 3 was about 32.4% and 6.2%. After ageing the comparison between cast and aged alloys was done and the results obtained showed enhancement in ultimate tensile strength for respective alloys after ageing process. The ultimate tensile strength of aged Alloy 1 was found to be 240 MPa and when compared with its cast counterpart the increase was about 31.9%. Further, the aged Alloy 2 and 3 with 8% and 12% Ni content showed values of 248 MPa and 267 MPa. On comparison with their cast counterparts the enhancement in the strength values for Alloy 2 and 3 was about 9.2% and 10.8% respectively. So from ageing point of view the ultimate tensile strength of all alloys was found to increase after ageing process. So in both cases of yield and ultimate tensile strength, the increase was attributed to three strengthening mechanisms, solution strengthening, grain boundary strengthening and work hardening [20,21]. First, the addition of Ni to the matrix tends to improve its strength which in turn depends on the size difference between solvent and solute. The size difference between the Ni and the matrix tend to create lattice distortion which in turn inhibit the dislocation motion thereby enhancing the strength. Secondly, increasing in Ni content led to grain refinement in alloys which is explained with the help of Hall-Petch relation. According to relation, lower the grain size higher will be the enhancement in the strength value. So from this it is quite clear that Alloy 3 which has highest Ni content has shown highest level of grain refinement and thereby highest strength as well. Finally, due to presence of Ni content and formation of precipitates the dislocation density will be higher for Alloy 3 compared with Alloy 1 and 2. This implies that aged Alloy 3 will exhibit higher flow stress when compared to other alloys in both cast and aged conditions.




**(a) Yield strength**




**(b) Ultimate tensile strength**




**(c) Elongation at break**

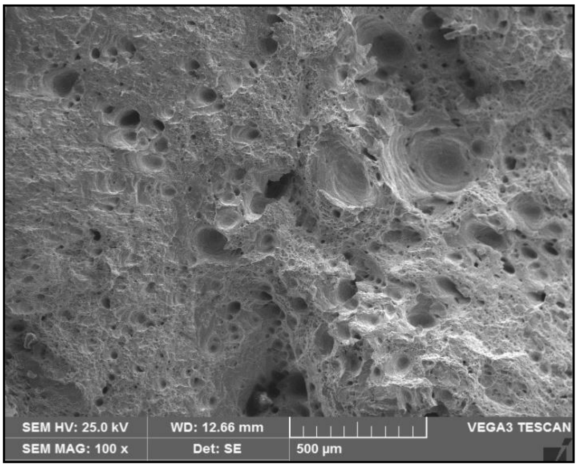
**Fig. 6 :** Tensile properties of cast and aged Cu-5%Zn alloys with varying Ni content

### *3.3.2 Elongation at break*

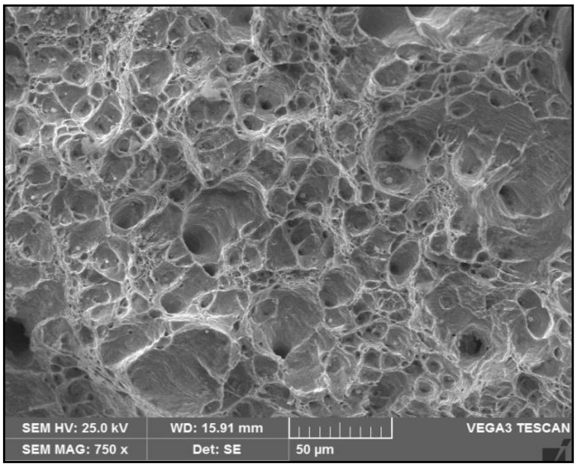
The elongation at break of Cu-5%Zn alloy samples with varying Ni content in both cast and aged conditions is shown in Fig. 6 (c). The elongation at break of cast Alloy 1 which contains 4% of Ni was found to be 24.4%. Further, with the increasing Ni content of 8% and 12%, the elongation at break of cast Alloy 2 and 3 were decreased to 17.5% and 15% respectively. The alloy with lowest Ni content showed highest elongation at break and when compared to Alloy 2 and 3, the elongation at break of Alloy 1 was about 28.2% and 38.5% higher. So strictly from Ni content point of view the elongation at break was found to be decreasing as Ni content was increased. On the other hand the comparison between cast and aged alloys was done and found that after ageing the elongation at break value increased for respective alloys. For instance, the elongation at break of aged Alloy 1 was found to be 32% and when compared with its cast counterpart the increase was about 31.1%. The elongation at break of aged Alloy 2 and 3 with 8% and 12% Ni content showed values of 20% and 16.8%. When compared with cast counterparts the increase in elongation at break was about 14.3% and 12% for Alloy 2 and 3 respectively. For the case of cast alloys the drop in elongation at break with the increase in Ni content was attributed to creation of number of interfaces between Ni and matrix. These interfaces act as point of stress concentrators and when tensile load is applied the cracks initiate at these regions first. So higher the Ni content, higher will be number of stress concentrators which imply that Alloy 3 will have lowest elongation value. Similar behavior was observed in Ref [19], where the authors found that addition of Ti particle to Cu-Zn alloy led to decrease in elongation value from 41.4% to 26.6%. Here also the authors proposed addition of Ti had adverse effect on the elongation of alloy. On the other hand the aged alloys also exhibited drop in elongation values which is attributed to the formation of $Cu_2NiZn$ precipitates. Though the increase in the Ni content helps in grain refinement but presence of $Cu_2NiZn$ precipitates has adverse effect on the elongation at break. This is due to the fact during application of tensile load these precipitates tend to breakaway easily from the matrix grains. Higher the number of precipitates higher will be the adverse effect on elongation of alloy which is why aged Alloy 3 showed lower elongation at break value.

### 3.4 Fracture studies

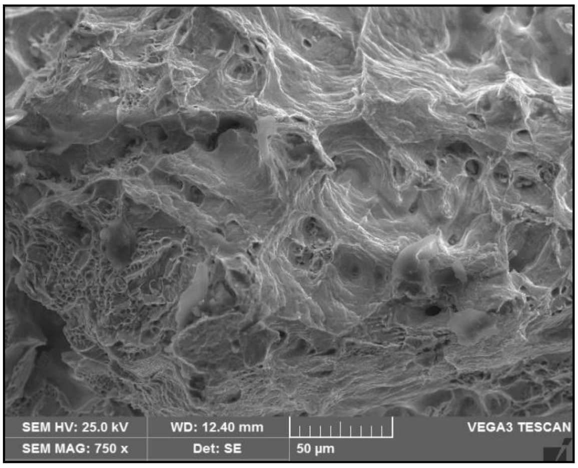
The tensile fracture surface of cast and aged alloys were studied using SEM and shown in the Fig. 7 (a) – (f). The fracture surface of Alloy 1 in both cast and aged condition is shown in Fig. 7 (a) and (b). From the figures it is quite clear that the alloy displayed ductile fracture which is quite evident from the dimples in the fractured surface. Large number of dimples and presence of tear ridges were quite evident for both the processing conditions which indicate that alloy has undergone extensive plastic deformation. The dimples were both small and large in size whose diameter was found to vary from 0.5 µm to 50 µm. Similar ductile features were reported by Pantazopoulos and Toulfatzis [22] on their work on brass rods having CuZn36Pb2As composition. The fibrous structure with large number of dimples was observed by the authors which they concluded to be man characteristics of ductile fracture. The highest elongation at break values for this alloy can be attributed to this failure mechanism. Further with the increase in Ni content to 8% and 12%, that is for Alloy 2 and 3 in both cast and aged conditions, the fractured surface displayed planar faceted like fracture and dimples. The presence of stress concentrator regions such interface between Ni particles and matrix and precipitates in case of aged alloys, the micro-void nucleation takes place. After growing to a critical size the voids across the samples tend to interconnect themselves leading to unstable crack propagation. This micro-void nucleation and their coalescence end up in the formation of dimples which represent ductile mode. In addition to this, the breaking of small Ni particles and precipitates from the matrix surface is not clearly visible. Overall the Alloy 2 and 3 displayed mixed mode of failure planar faceted like fracture and dimples.



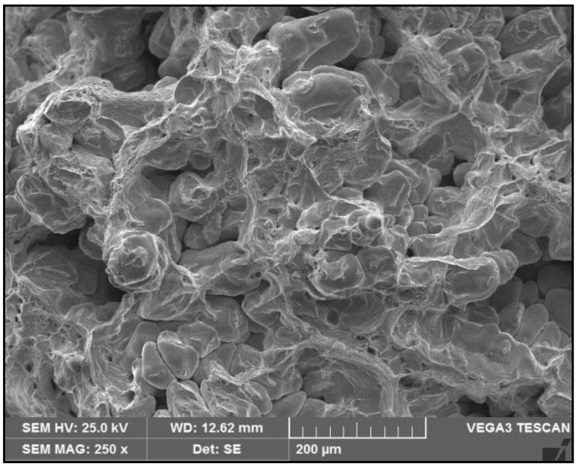

(a) Alloy 1



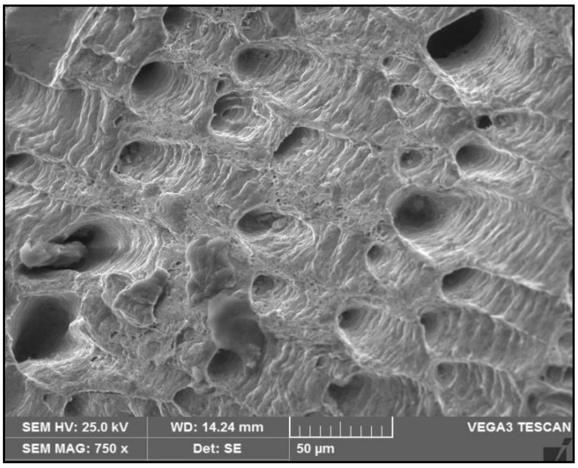

(b) Alloy 1



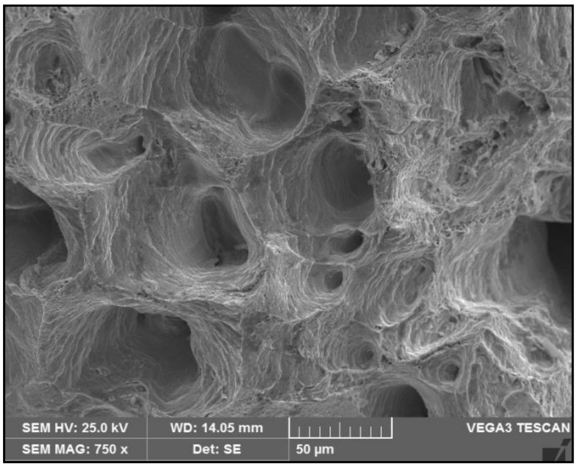

(c) Alloy 2




(d) Alloy 2




(e) Alloy 3




(f) Alloy 3

**Fig. 7:** SEM micrographs showing tensile fracture surface of (a,c,e) cast and (b,d,f) aged samples (4 hours)

### 4.0 Conclusions

This work involved studying the effect of Ni on the microstructure, microhardness and tensile properties. In addition to this, the SEM analysis was also conducted to check what type of failure did the Cu-5Zn alloys have undergone. Overall the main observations and concluding remarks pertaining to them are presented below,

- In case of cast alloys, due to low Zn content only α-phase but the β-phase or dendritic structure was not seen. Increasing Ni particles and mechanical stirring led to conversion of dendritic structure to fine equiaxed grains. The aged alloys also showed similar structure and in addition to this $Cu_2NiZn$ precipitates were seen in the matrix.

- The microhardness of as cast alloys tends to increase with increasing Ni particle content. Highest microhardness was for both cast and aged condition was observed for alloy with 12% Ni content. The enhancement was attributed to grain refinement and formation of $Cu_2NiZn$ precipitates.
- The yield and ultimate tensile strength of both cast and aged alloys increased with the increasing Ni content and formation of precipitates. The strengthening mechanisms responsible for improvement in strength were solution strengthening, grain boundary strengthening and work hardening.
- Elongation at break of cast and aged alloys were found to decrease with increasing Ni content. The decreasing values were attributed to formation of interfaces due to introduction of Ni particles and breaking of precipitates from matrix.
- The tensile fracture analysis of alloys analyzed using SEM showed ductile fracture for alloy with low Ni content for both cast and aged conditions. The alloys with higher Ni content showed mixed mode failure.

**References**


**[1].** J.R. Davis, Copper and Copper Alloys, ASM Specialty Handbook, ASM International, Materials Park, OH, 2001.

**[2].** M. Li, S.J. Zinkle, Physical and Mechanical Properties of Copper and Copper Alloys, In: R.J.M. Koning (ed), Comprehensive Nuclear Materials, Elsevier Ltd., 2012, pp. 667-690.

**[3].** D. Zhu, M. Song, J. Chen, M. Tu, H. Pan, Electrical conductivity of Cu-Li alloys, Journal of Central South University of Technology 11 (2004) 252-254.

**[4].** K.C. Nnakwo, F.O. Osakwe, B.C. Ugwuanyi, P. A. Oghenekowho, I.U. Okeke, E.A. Maduka, Grain characteristics, electrical conductivity, and hardness of Zn-doped Cu-3Si alloys system, SN Applied Sciences 3 (2021) 829.

**[5].** S. Abbas, S. Seo, K. Park, B. Kim, T. Kim, Effect of grain size on the electrical conductivity of coppereiron alloys, Journal of Alloys and Compounds 720 (2017) 8-16.

**[6].** H. Yang, Z. Ma, C. Lei, L. Meng, Y. Fang, J. Liu, H. Wang, High strength and high conductivity Cu alloys: A review, Science China Technological Sciences 63 (2020) 2505-2517.

**[7].** P.G. Koppad, K.T. Kashyap, V. Shrathinth, T.A. Shetty, R.G. Koppad, Microstructure and microhardness of carbon nanotube reinforced copper nanocomposites, Materials Science and Technology (United Kingdom) 29 (2013) 605-609.

**[8].** P.G. Koppad, H.R. Ram, K.T. Kashyap, On shear-lag and thermal mismatch model in multiwalled carbon nanotube/copper matrix nanocomposites, Journal of Alloys and Compounds 549 (2013) 82 - 87.

**[9].** M. Adineh, H. Doostmohammadi, R. Raiszadeh, Effect of Si and Al on the microstructure, mechanical properties and machinability of 65Cu-35Zn brass, Iranian Journal of Materials Science & Engineering 16 (2019) 21-32.

**[10].** M. Adineh, H. Doostmohammadi, Microstructure, mechanical properties and machinability of Cu-Zn-Mg and Cu-Zn-Sb brass alloys, Materials Science and Technology 35 (2019) 1504-1514.

**[11].** W. Chen, Y. Jia, J. Yi, M. Wang, B. Derby, Q. Lei, Effect of addition of Ni and Si on the microstructure and mechanical properties of Cu–Zn alloys, Journal of Materials Research 32 (2017) 3137-3145.

**[12].** I. Basori, I.N.K. Ali, S. Sirojuddin, S.T. Dwiyati, Y. Sari, Study on the aluminum addition to the microstructure and mechanical properties of Cu-10Zn alloys produced by gravity casting, IOP Conf. Series: Materials Science and Engineering 1098 (2021) 06204.

**[13].** W. Kurz, D.J. Fisher, Fundamentals of solidification. Switzerland: Trans Tech Publications; 1992.

**[14].** C. Rotty, A. Mandroyan, M.-L. Doche, J.Y. Hihn, Electropolishing of CuZn brasses and 316L stainless steels: Influence of alloy composition or preparation process (ALM vs. standard method), Surface & Coatings Technology 307 (2016) 125-135.

**[15].** K.K. Alaneme, S. Umar, Mechanical behaviour and damping properties of Ni modified Cu-Zn-Al shape memory alloys, Journal of Science: Advanced Materials and Devices 3 (2018) 371-379.

**[16].** M.J. Dianez, E. Donoso, J.M. Criado, M.J. Sayagues, G. Diaz, L. Olivares, Study by DSC and HRTEM of the aging strengthening of Cu-Ni-Zn-Al alloys, Materials and Design 92 (2016) 184-188.

**[17].** N.Z. Khan, A. Khan, A. Shakoor, K. Azam, Manufacturing defects of brass products and suggested remedies, International Journal of Innovative Science, Engineering & Technology 2 (2015) 497-514.

**[18].** W. Gao, S. Xing, Y. Wang, Effect of lanthanum addition on microstructure and hardness of brass alloys produced by rheological squeeze casting, Journal of Rare Earths, Available online 31 December 2021, https://doi.org/10.1016/j.jre.2021.12.010.

**[19].** S. Li, H. Imai, K. Kondoh, Microstructure, phase transformation, precipitation behavior and mechanical properties of P/M Cu40Zn-1.0 wt% Ti brass alloy via spark plasma sintering and hot extrusion, Journal of Materials Science & Technology 29 (2013) 1018-1024.

**[20].** W. Chen, M. Wang, Z. Li, Q. Dong, Y. Jia, Z. Xiao, R. Zhang, H. Yu, A novel Cu-10Zn-1.5Ni-0.34Si alloy with excellent mechanical property through precipitation hardening, Journal of Materials Engineering and Performance 25 (2016) 4624-4630.

**[21].** J. Li, H. Ding, B. Li, W. Gao, J. Bai, G. Sha, Effect of Cr and Sn additions on microstructure, mechanical-electrical properties and softening resistance of Cu–Cr–Sn alloy, Materials Science & Engineering A 802 (2021) 140628.

**[22].** G.A. Pantazopoulos, A.I. Toulfatzis, Fracture modes and mechanical characteristics of machinable brass rods, Metallography, Microstructure, and Analysis 1 (2012) 106-114.