Fabrication of Highly Strained Stainless Steel Powder Reinforced Copper Based Hybrid Composite

Krishna Chandra Mishra¹, Er. Vivek Khokhar²
M-Tech Scholar¹, HOD²
Department of Mechanical Engineering
GITAM, Haryana, India

Abstract:
Copper materials have wide applications due to its very good electrical conductivity, thermal conductivity and corrosion resistance, but due to its poor mechanical properties and tribological properties, its application is restricted in the structural materials and high contacting parts with higher application of load. So keeping in mind to improve its mechanical and tribological properties without much affecting its natural properties. This work is totally focused on fabrication of such copper based hybrid composites which must have good electrical and thermal conductivity with better mechanical and tribological properties. For development of such hybrid materials, commercial copper is taken as matrix and tungsten carbide, highly strained stainless steel (HSSS), chromium are taken as reinforcement in a definite weight proportion, the stir casting technique is utilized to develop such composites.

Keywords: tribological properties, composite material, EDAX spectrum, Wear Test, Tensile Strength.

1. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. In the two constituents one is the matrix and other is reinforcement.

1.1 THE MAIN ADVANTAGES OF COMPOSITE MATERIALS:

- High strength
- Better Electrical conductivity
- Better Thermal conductivity
- Weight Behavior at extreme temps.
- Fatigue Acoustical insulation
- Vibration damping Aesthetics
- Resistance to wear Resistance to corrosion

1.2 CLASSIFICATION OF COMPOSITES:

- **Particulate composites** have one or more material particles suspended in a binding matrix. A *particle* by definition is not “long” vis-à-vis its own dimensions.
- **Fibrous composites** have fibers of reinforcing material(s) suspended in binding matrix. Unlike particles, a fiber has high length-to-diameter ratio, and further its diameter may be close to its crystal size.

2. LITRERY REVIEW

Synthesis of copper based metal matrix hybrid composite in which commercial copper is used as matrix materials and highly strained stainless steel particles and chips are taken as filler materials including tungsten carbide and chromium as filler. This work is done on extracting the ideas from the following literatures review; some of the literature review and its conclusion are depicted below in fascinating manner.

- M. R. Akbarpour et al concluded that the developed copper based hybrid composites using nanoparticulates of SiC and CNT with minimal porosity. And homogenous dispersion of CNTs during short time mechanical milling and retarded grain growth during HP was seen in the presence of SiC nano particles. And it is also observed that the mechanical properties evaluation of the composites showed considerable enhancement in the micro hardness, Young’s modulus and yield strength as a result of ultrafine grained microstructure, high density of planar defects and homogeneous distribution of reinforcements.
- While H. Sarmadi et al put their observation that the fabrication of copper–graphite composites by friction stir processing (FSP) is possible. And using this technique leads to more homogenous distribution of particles in surface of composite and prevents particle changing into clusters which was the most important problem in prior techniques such as powder metallurgy and centrifugal casting. It is also reveals that the Friction coefficient is dramatically decreased with increase in Graphite content. Wear loss of specimens is decreased with increase in graphite.

3. EXPERIMENTAL WORK

3.1 SYNTHESIS OF COPPER BASED HYBRID COMPOSITE:

Table 1 shows the compositions of the developed copper based metal matrix hybrid composites. The copper materials is taken as matrix according to weight percentage which is shown in the table where highly strained stainless steel (HSSS) particles and curl chips, tungsten carbide (WC) and chromium (Cr) are taken as reinforcing materials according to their weight percentage that are shown in Table 1. Tungsten carbide and chromium are taken as a fixed quantity in each their weight percentage which is shown in the Table1. Tungsten carbide and chromium are taken as reinforcing materials according to weight percentage that are shown in the Table1. Tungsten carbide and chromium are taken as reinforcing materials according to weight percentage that are shown in the Table1. Tungsten carbide and chromium are taken as reinforcing materials according to weight percentage that are shown in the Table1. Tungsten carbide and chromium are taken as reinforcing materials according to weight percentage that are shown in the Table1.
### 3.2 Technique Used

- **Stir Casting Method is used:**

  Stir casting method is used to produce the casting ingot of copper based hybrid composites Cu-1WC-2steel powder-2Cr, Cu-1WC-3steel powder-2Cr, Cu-1WC-4steel powder-2Cr.

### Following steps are involved:

1. The temperature of furnace kept at 1200 °C for melting of commercial copper, since the melting temp of copper is 1084°C but this high temperature is used to increase its flow ability of molten state and for proper stirring.
2. Steel powder (FeC), Chromium (Cr) and Tungsten Carbide (WC) powder were kept in furnace at 100 deg C for one and half Hrs for evaporating of some moisture contents and vaporized materials.
3. When the temp of furnace reaches to 1200 °C, the dry powders are poured into the molten commercial copper.
4. After pouring the reinforcing powders the molten solution is stirred for 5 minute at-300 RPM (Approximately).
5. Then the molten hybrid composite is poured into rectangular permanent mould and leaves it in mould for air cooling for 30 min.
6. After 30 min air cooling of cast ingot that is cooled in water then final cast ingot is ready for various characterizations.

### 3.3 Tensile test:

Tensile testing is done on Instron tensile testing machine. Tensile testing is a destructive test process that provides information about the tensile strength, yield strength and ductility of a material. The tensile test or tension test involves applying an ever-increasing load to a test sample up to the point of failure. The process creates a stress/strain curve showing how the material reacts throughout the tensile test. The test sample is securely held by top and bottom grips attached to the tensile or universal testing machine. During the tension test, the grips are moved apart at a constant rate to stretch the specimen. The force on the specimen and its displacement is continuously monitored and plotted on a stress-strain curve until failure. The measurements tensile strength, yield strength and ductility are calculated by the technician after the test specimen has broken. The test sample is put back together to measure the final length, and then this measurement is compared to the pre-test or original length to obtain elongation. The original cross section measurement is also compared to the final cross section to obtain reduction in area.

### 3.4 Hardness Test:

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a test force of between 1gf and 100kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surfaces of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation. With modern advances in technology, PCs and software development, it is now possible to offer automatic indentation measurement. This has the benefit of eliminating any operator influence over the result, reducing R&R (repeatability and reproducibility) and uncertainty budgets. Automatic test surface focusing, motorized XY tables and automatic effective case depth determination are common place in advanced laboratories around the world who require the latest technology offering fast, reliable and traceable testing.

### 3.5 Wear Test:

Wear is a process of removal of material from one or both of two solid surfaces in solid state contact. As the wear is a surface removal phenomenon and occurs mostly at outer surfaces, it is more appropriate and economical to make surface modification of existing alloys than using the wear resistant alloys. Dry sliding wear tests for different number of specimens was conducted by using a pin-on-disc machine. In this experiment, the test was conducted with the following parameters:

- **1. Load**
- **2. Speed**
- **3. Distance**

In the present experiment the parameters such as speed, time and load are kept constant throughout for all the experiments. These parameters are given in Table 2.

### Table 2.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Pin material</th>
<th>Disc material</th>
<th>Pin dimension</th>
<th>Sliding speed (m/s)</th>
<th>Normal load (N)</th>
<th>Sliding distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CC, HC-1</td>
<td>EN 31 steel</td>
<td>Cylinder with diameter 8mm height 30 mm</td>
<td>1.304</td>
<td>10, 20, 30, 40</td>
<td>5000</td>
</tr>
<tr>
<td>2</td>
<td>CC, HC-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>CC, HC-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this study, Pin-on-Disc testing method was used for tribological characterization. The test procedure is as follows:

- Initially, pin surface was made flat such that it will support the load over its entire cross-section called first stage. This was achieved by the surfaces of the pin sample ground using emery paper (80 grit size) prior to testing
- Run-in-wear was performed in the next stage/second stage. This stage avoids initial turbulent period associated with friction and wear curves
- Final stage/third stage is the actual testing called constant/ steady state wear. This stage is the dynamic competition between material transfer processes (transfer of
material from pin onto the disc and formation of wear debris and their subsequent removal). Before the test, both the pin and disc were cleaned with ethanol soaked cotton (Surappa et al 2007). Before the start of each experiment, precautionary steps were taken to make sure that the load was applied in normal direction.

4. RESULT AND DISCUSSION

The morphology of the reinforcing particles of highly strained stainless steel [HSSS], tungsten carbide [WC] and chromium [Cr] are very fascinating and self explaining which are depicted in the Fig. 1. Fig [a], [b] and [c] are the scanning electron microscopic images of the HSSS, WC and Cr respectively at 500X while [a’] and [b’] are the morphology of HSSS and WC at 2000X. The strained chips can be easily observed in the Fig. [a] and [a’] both.

4.1 EDAX spectrum of the reinforcing particles

Energy dispersive spectrum of the reinforcing particle is shown in the Fig. 2. The spectrum of the HSSS, WC and Cr are depicted in the fig [a], [b] and [c] respectively. Energy peak of chromium is also observed in the spectrum of chromium including some carbon peak which is attributed to the carbon tape which was used as substrate for the chromium while testing.

4.2 EDAX spectrum of the developed hybrid composite and commercial copper:

The energy dispersive spectrum of the commercial copper, hybrid composite-1, hybrid composite-2 and hybrid composite-3 are shown in the Fig. 3 [a], [b], [c] and [d] respectively. From the spectrum, it is observed as the weight percentage of the highly strained stainless steel increases in the copper their weight percentage and atomic percentage peak value also increases in the spectrum that are clearly shown in the figure.

4.3 XRD pattern of the developed hybrid composites and commercial copper:

X-rays diffraction pattern of the commercial copper, hybrid composite-1, hybrid compoite-2 and hybrid composite-3 are stacking to each other that is shown in the fig. 4. In figure, it is observed that hybrid composite-1 and hybrid composite-2 has not shown any extra peak other than the copper, it is attributed to the low weight percentage of reinforcement that is not possible to observed by the x-rays diffraction or the intensity of peak of the reinforcing materials are relatively so small so it is not easy to observe in X-rays diffraction pattern. But it is observed that there is little extra peaks other than copper are shown in the X-rays diffraction pattern of the hybrid composite-3, it means if we start reinforcing more than four weight percentage of HSSS in copper then the possibility of finding of the reinforcing materials peak in x-rays diffraction pattern. Here in the XRD pattern of the hybrid composite-3, it is not easy to observe the intensity peak of the other elements also.
4.4 Microstructure of the commercial copper and developed hybrid composites material:
The optical micrograph of the commercial copper, hybrid composite-1, hybrid composite-2 and hybrid composite-3 are shown in the Fig. 5 [a], [b], [c] and [d] respectively. It is observed that the optical microstructures of the hybrid composite contains some austenitic structures like stainless steel that means the commercial copper showing the presence of the HSSS reinforcement which can seen in the figure 5 [b]. While the optical microstructure of the hybrid composite-2 shows there are some grains refinement as comparative to commercial copper and hybrid composite-1 and also the hybrid composite-2 and hybrid composite-3 show some small fine particle distributed homogeneously on the surface that are shown in the figure 5 [c] and [d].

Figure 5. Optical microstructures of the commercial copper and developed hybrid composites material

4.5 Density:
The density of the commercial copper and developed hybrid composites are measured using Archimedes principle that are shown in the Fig. 6. From the figure, it is concluded that the density of the developed hybrid composites decreases as the percentage composition of the highly strained stainless steel increases in the copper matrix. It is because of the increase in the number of voids in the composite materials, the increase in the voids are attributed to the reinforcement of the irregular and uneven particles and chips which are greater in size than the voids generated. The addition of the low density highly strained stainless steel in copper matrix is one of the possible reasons to lowering the density of the developed hybrid composites. Since there is direct relation in between density and strength of the materials that is as the density decreases the strength of the materials decreases but in this case the strength of the developed materials increases, it is attributed to the reinforcement of the hard ceramic particles and highly strained stainless steel particles and chips.

Figure 6. Density of the materials

4.6 Hardness
Vickers hardness of the commercial copper and developed hybrid composites are shown in the Fig. 7. Figure shows that as the weight percentage of the HSSS increases the Vickers hardness value also increases. It is attributed to the reinforcement of the harder materials like- HSSS, WC and Cr into softer copper matrix materials. The hardness value is taken as the average value of the five hardness readings which validate the results and error was also calculated according to the error calculations. The hardness improvement of the developed hybrid composites are attributed to the involvement of the several hardening mechanism like- load transfer effect, hall-petch mechanism and elastic modulus mismatch of the different reinforcing particles and copper metal matrix.

Figure 7. Vickers hardness of materials

4.7 Tensile strength
The behavior of the tensile strength of the developed hybrid composites and commercial copper are shown in the Fig-8. From the figure, it is observed that the tensile strength of the developed hybrid composite materials increases as the reinforcing of the HSSS increases in the copper matrix. It is attributed to the reinforcement of the hard ceramics and HSSS materials which restrict to the plastic deformation they act like a pin point which resist to the dislocations in the materials up to a breaking load.

Figure 8. Behaviour of the tensile strength of different materials

4.8 Wear results (Weight loss with sliding distance)
The behavior of the weight loss with sliding distance of the commercial copper, hybrid composite-1, hybrid composite-2 and hybrid composite-3 at 9.81N, 19.62N, 29.43N and 39.24N
are shown in the Fig. 9[a], 9[b], 9[c] and 9[d] respectively. In each and every figure, it is observed that as the sliding distance increases the weight loss increases for all the materials at all the normal load but the overall weight loss of the hybrid composite-3 is least in all the cases, it is attributed to the increase in the percentage of the HSSS reinforcement in the copper matrix including with tungsten carbide one of the hardest materials.

![Figure 9(a)- Behavior of the weight loss with sliding distance at 9.81N](image)

![Figure 9(b)- Behavior of the weight loss with sliding distance at 19.62N](image)

![Figure 9(c)- Behavior of the weight loss with sliding distance at 29.43N](image)

![Figure 9.d- Behavior of the weight loss with sliding distance at 39.24N](image)

4.9 Wear result (Weight loss with normal load)
The behavior of the weight loss against the normal load of the commercial copper, hybrid composite-1, hybrid composite-2 and hybrid composite-3 are shown in the Fig. 10. It is observed that the weight loss of the materials increases as the applied normal load increases but the weight loss of the composite materials are relatively very low, the hybrid composite-3 has a magnificent resistant to weight loss. It is attributed to the harder ceramic materials and specific role of the HSSS in the copper matrix, since the normal load increasing that need a positive response of the high weight loss usually it is happening in the wear pin materials but HSSS and WC play a vital role to resist the further loss. Since it is already explained above initially matrix get contact with the counter disc but after wear of matrix the harder reinforcements get exposure which stop further wear due to its inherent harder properties.

5. CONCLUSION

From the present work it can be conclude the following points:
- Highly strained steel powder reinforced copper based hybrid composite can be prepared using the stir casting technique, involving the above steps.
- Microstructure of both commercial copper and hybrid composites are different that shows they must have their different properties.
- Tensile strength of copper based hybrid is very good as compare to pure copper according to other sources for the strength of pure copper.
- Scanning electron microscope morphology of the reinforcing particles discloses its hidden characteristics about its shape and sizes.
- Weight loss against sliding distance is very low in developed copper based hybrid composite comparative to commercial copper matrix.
- Behavior of weight loss with the normal load is also very low in hybrid composite comparative to copper matrix.

6. FUTURE WORK:
- Perform corrosion test of copper based hybrid composites and commercial copper.
- Electrical and thermal conductivity measurement of the developed copper based hybrid composite. Worn surface analysis using Atomic Force Microscope.
7. REFERENCES


