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Dry sliding wear behavior of hot forged and annealed Cu–Cr–graphite in-situ composites

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ABSTRACT

In the present investigation Cu based composites have been developed through solidification processing by addition of a fixed amount of Cr and three different amounts of graphite viz. 2, 3 and 4 wt.%. All of the cast composites have been hot forged and annealed. Dry sliding friction and wear behavior of all the composites in as cast, hot forged and annealed conditions has been investigated by sliding against a counterface of SAE 4615 steel disc under ambient conditions using a pin-on-disc machine. The sliding wear tests have been conducted at four different normal loads 10, 20, 30, and 40 N and a constant sliding speed of 0.786 m/s. The primary focus of the study is to understand the effect of hot forging and annealing after hot forging, on the wear characteristics of these composites. For a given normal load, the cumulative volume loss increases linearly with increasing sliding distance for all materials. The wear rate has also been found to increases linearly with increasing normal load. Wear rate of Cu–4Cr–4G composite is significantly lower than that of all other materials either hot forged or annealed. Average coefficient of friction decreases with increasing the normal load and the graphite containing composite shows the lower average coefficient of friction than the other materials. Worn surface of the pin specimen show significant formation of transfer layer for hot forged and annealed Cu–4Cr–4G composite.

1. Introduction

The composites in which the reinforcing phase is synthesized within the matrix during fabrication are called in-situ composites. Various techniques have been evolved for the fabrication of composites reinforced by ceramic particles generated in situ during processing. which can be categorized in terms of the state of the reacting phases such as gas–liquid, liquid–solid, liquid–liquid. The present study deals with liquid–solid process, in this process, solid reactants (elements or compounds) react with some component in the melt or with the melt to form in-situ ceramic reinforcements. It is quite important to understand the mechanisms responsible for the development of morphology while tailoring a composite system for a specific application. In-situ generated reinforcement has a variety of morphologies, ranging from discontinuous to continuous, and the reinforcement may either be ductile or brittle. In-situ composites offer more advantages over those produced by ex-situ methods which include smaller reinforcement particle size, single-crystal reinforcements, clean and uncontaminated particle–matrix interfaces with possibility of higher interfacial strength and improved wettability, better particle-size distribution, long-term stability, improved resistance to corrosion and thermodynamically stable particles that are weldable and castable.

High-strength Cu alloys may be achieved by reinforcing or dispersing ceramic particles, e.g. oxides, borides, carbides, in the copper matrix and these alloys work as dispersion strengthened (DS) copper alloys. A lot of research has been done on synthesis and characterization of Al- and Ti-based composites, but only a few studies are available for Cu-based in-situ composites. Tu et al. [1] have pointed out that the tensile strength of Cu based in-situ composites obtained by mechanical alloying (MA) or spray forming process increases with increasing particle content whereas the reverse is true for ductility. It has also been indicated that TiB_2 particle reinforcement is more effective than Al_2O_3 in improving the mechanical strength of copper at elevated temperatures [1]. Sun et al. [2] studied the effect of addition of 0.5% silicon on the microstructure and mechanical properties of Cu–15Cr alloy in as cast and drawn conditions. It has been reported that the strength of Cu–15Cr–0.5Si in-situ composite is higher than Cu–15Cr in-situ composite at the same interphase spacing due to higher hardness of Cr phase resulting from the effective hardening from addition of Si.

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Table 1
Designation, hardness and density of materials.

S.No.	Designation	Hardness (MPa)			Density in 10^3 kg/m^3		
		As cast	Hot forged	Annealed	As cast	Hot forged	Annealed
1	As received wrought copper	80.82	86.8	67.5	8.4	8.8	8.8
2	Cast copper	61.48	79.0	56.8	8.08	8.12	8.12
3	Cu–4Cr	64.12	105.9	62.9	9.68	10.0	10.0
4	Cu–4Cr–2G	51.84	68.7	63.1	8.12	10.15	10.21
5	Cu–4Cr–3G	63.78	92.8	64.8	8.05	9.59	9.6
6	Cu–4Cr–4G	82.71	112.9	68.9	8.09	9.16	9.5

Wear behavior of materials is a very complicated phenomenon due to many variables such as sliding parameters, materials properties, abrasive effects and lubricating conditions etc. Tjong and Ma [3] have claimed that the excessive delamination of surface layers of copper leads to a high wear loss, which increases with increasing sliding distance. Addition of 20 vol.% SiC particles to copper matrix considerably increases the hardness of a composite and thereby, results in a reduction of the extent of plastic deformation of the matrix and wear loss of the composite is also reduced considerably. Tjong et al. [4] observed that copper composites reinforced with TiB_2 particles exhibit superior wear resistance compared to that in pure copper. Moustafa et al. [5] reported that composites made by Cu-coated and uncoated graphite possess lower wear rates and friction coefficients than those made from pure copper. It has been stated that the higher the graphite content in a composite having either Cu-coated or uncoated graphite, the lower the observed coefficient of friction. Saka et al. [6] studied the frictional behavior of graphite fiber-reinforced MMCs and indicated that a higher initial friction is due to the adhesion between the matrix metal and the counterface before the formation of intervening layer of graphite on the sliding surface. Rohatgi et al. [7,8] also concluded that during sliding contact of various materials with graphite containing com-

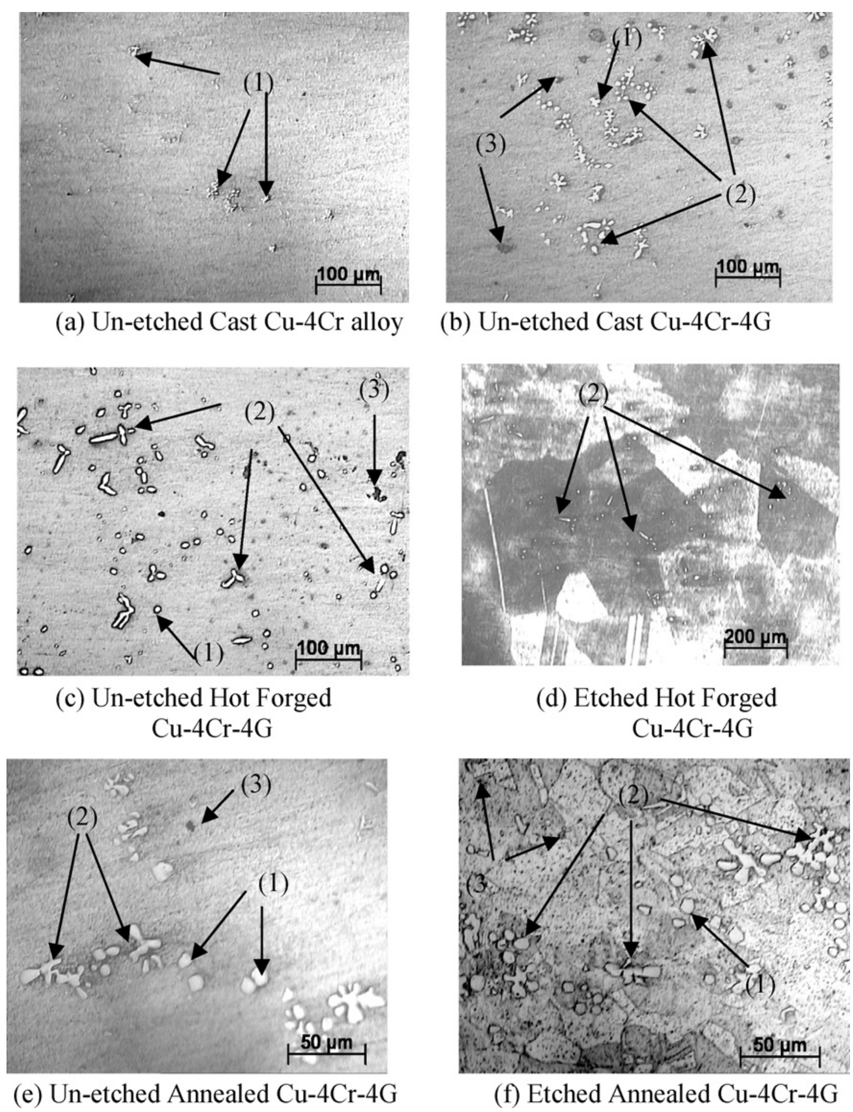

Fig. 1. Unetched and etched optical micrographs showing microstructure of Cu–4Cr and Cu–4Cr–4G composite, chromium marked by (1), carbides marked by (2) and graphite marked by (3).