INTRODUCTION

It has been some time now since the interest of material developers is constantly being diverted towards utilizing composite materials, to solve problems in a fast growing industry increasingly demanding new materials with unprecedented properties. In order to supply an ever-growing highly competitive market whose costumers urgently demand products of higher performances, of economic feasibility, of miniaturized nature, with lower density, and of longer life. Since, these end-users need to match others and even race to gain supremacy in fields of strategic and advanced applications. Their main incentive is the attractive properties of composites, and the possibility of designing costume-made materials for specific application.

In general, the strength of composites stem from their structural inhomogeneity purposely designed and induced in a matrix to modify a property in question to a desired shape or value in order to fulfil a certain required specification. These inhomogeneities are supposed to be evenly distributed and strongly bound within the host matrix, such that the overall composite would behave as a single unit. In the field of composite technology any property of a specific matrix may be purposely modified to suite a desired application by selecting an appropriate inhomogeneity to be induced within this matrix. However, predesigned modification of mechanical properties of a specified matrix would strongly depend on the properties of the material of the induced inhomogeneity in addition to its geometry and dimensional ratios. Since, one type of geometry may modify certain mechanical properties more effectively than others, fiber shaped induced inhomogeneity may lend support (reinforce) to a matrix subjected to tensile stresses much more effectively than particulated fillers, i.e., not only not lend the desired support but might cause a deterioration of the tensile strength of the host matrix which indicates the importance of the geometrical factor in real application.

Traditionally, most metal-matrix composites are mainly produced by a melting and casting techniques or by powder metallurgy, which both are most suited for to be reinforced by short fibers. However, to melt a plain matrix involves the use of somehow extensively high temperatures, depending on the melting point of the metal matrix. Moreover, to introduce the fiber to the molten metal matrix may subject these fibers to a number of risks:

- Having a chemical reaction with the matrix material.
- Suffering a permanent shape deformation.
- Getting oxidized at high temperatures.

Each of the above possibilities would drastically modify the chemical or geometrical properties of the fibrous filling material, which may undermine its functional ability to reinforce the host matrix and thus cancels the basic principle of reinforcement and the structure of the composite. On the other hand, composites may also be produced via an electrochemical forming process, where a metal-matrix may be deposited or built around long reinforcing fibers or meshes at temperatures fairly close to room temperature. Thus, the expected or possible damage of the reinforcing fibers would be avoided.

In the present work, a nickel matrix is deposited by an electrochemical forming technique, where a special mold/fiber-holder is designed to hold the long fibers in a desired configuration. This fiber-holder is then used as a cathode in a Watts deposition bath. The resulting composites produced at various deposition conditions (deposition current densities and deposition bath temperature), are subjected to thermal and mechanical treatments primarily in the aim of promoting the internal compaction. The resulting microstructure and the mechanical nature of these treated composites is investigated accordingly to study the effect of these secondary treatments.
EXPERIMENTAL TECHNIQUES

A number of long carbon fibers, properly cleaned by acetone, arranged in an equidistant parallel configuration. All fixed in a rectangular-shaped frame-mold shown in figure (1). Ensuring that electrical conduction is only limited to the carbon fibers and not to the elastic frame material. This frame-like mold is dipped in the Watts bath deposition solution and used as a cathode in the electrochemical forming process. Whereas, a sheet of pure nickel metal is used as an anode in the bath. D.C currents of various densities is supplied by a power supply capable of supplying (1-15) Amperes at voltages of up to 10 volts across the terminals of the bath. Accordingly, nickel is deposited around the conductive fibers building up a nickel matrix around the prefixed reinforcing fiber configuration mentioned above, thus forming a carbon fiber reinforced nickel composite. The solution in the bath used in the Watts bath is continuously stirred to ensure temperature homogeneity. Table (1) below, exhibits the chemical composition of the deposition solution used in the Watts bath, in addition to that it shows the operational conditions maintained through the deposition process. Raw/as deposited composites are normally found to be porous as discussed below in the results and discussion part. They are subjected to thermal-mechanical combined regimen of treatment in an attempt to compact the bulk as much as possible and eliminate the residual porosity. The treatment included heating at a specific temperature for period of one hour prior to being immediately forged, and this thermal treatment would be repeated if a second forging pass is desired. Thus, multiple forging passes would involve multiple heat treatments accordingly are performed. Microstructures of the as deposited and those treated by the above thermal--mechanical process are investigated by standard optical microscopy using maximum magnification power on samples of 1cm in width and 2cm in length. Tensile strength tests are made in accordance to ASTM-standard numbered D3552, while bending tests are performed in accordance to ASTM-standard number D790. Impact strength tests are performed in accordance to ASTM-standard number E23.

ABSTRACT

In the work, a metal=matrix composite is electrochemically formed by depositing a nickel-matrix around a prearranged configuration of long reinforcing carbon fibers. The microstructure shows columnar nickel-grain structure in which the grains are attached by surrounding the long carbon fibers in a polarized manner. It also shows the presence of giant vertical pores when certain regions are cut-off from the depositing current, thus prevented from being filled up by the deposition process. The resulting composites are treated thermomechanically (heat treatment and forging) in an attempt to reduce the inherent porosity, and this secondary treatment has modified the microstructure heavily. This has changed much of the structural and mechanical nature of the original composite like the load-deflection behavior, the flexural modulus, the tensile strength, and the impact strength of both plain- matrices and those of reinforced composites.

Results and Discussion

A nickel-matrix is electrochemically deposited around a predesigned configuration of long carbon fibers to manufacture a metal-matrix composite without using high temperatures. The microstructure of the resulting composite consists of columnar nickel-grains polarized in a radial manner around individual carbon fibers of the above mentioned configuration as shown in fig. 1. The grains are totally aligned along the direction of the deposition current, which flows through the whole surface area of the reinforcing fibers. Moreover, it may also be noticed that the sizes of nickel grains in direct contact with individual carbon fibers surface and those residing in rows very close to it are explicitly finer than those residing in rows further away from the fiber surface. This is due to

The fact that the surface area of individual fibers is constantly increasing by a continued process of nickel grains deposition. Hence, the corresponding current density would vary in accordance with the actual value of the total surface area exposed to the deposition current. This would result, in different grain sizes being deposited at different distances from the reinforcing fiber surface. Since, higher
current densities would deposit finer grains and lower current densities would deposit coarse grains (x). Moreover, one may notice how cylinder cal-shaped accumulations around carbon fibers enclose large size voids (pores) in the overlap regions. Formed as isolated regions after being sealed off from the deposition current flow, and accordingly deprived from being filled up by deposited nickel. In an attempt to enhance the compaction of these composites, secondary processes are applied where composites are separately subjected to heat treatments at temperatures of 450°C, 550°C, and 650°C for a period of one hour. And the photomicrographs exhibited in fig.2 indicate that the treatment at 450°C has done nothing to modify the original microstructure. However, higher temperatures (550°C and 650°C) seem to initiate a grain growth process which inflicted an explicit deformation on the original microstructure to various degrees depending on the temperature as shown in fig.2. The cracks shown in the figure are mainly due to deferential stresses induced by the grain growth process itself. Moreover, the composites are subjected to a number of forging passes (1 to 3 passes) in between which the composite is heat treated at the relevant temperatures. Hence, in this case the material receives a multi-fold heat treatment in addition to mechanical treatment each time it is subjected to forging, yielding the observed cracks and the gradual grain-shape transformation.

This combined treatment has initiated a continuous transformation process of columnar grains into ordinary grains as exhibited by fig.4 show how load-deflection behavior would drastically modify upon heat treatments, where the ductility of the plain nickel matrix is enhanced with increased heat treatment temperature.

The load-deflection behavior of the composite as shown in fig.5 , where it clear that the untreated composite is also highly stressed and the respective ductility seem to enhance with increasing heat treatment temperature. One may also notice that the ductility and the tensile strength decline with increasing number of forging passes, which may correlate with what has been said about fig.3 where the continued crack growth is expected to reduce the tensile strength. This may be further confirmed by fig.6 where the tensile strength explicitly declines with increasing heat treatment temperature, in addition to the increased number of forging passes. However, the forging passes seem to take a more effective role in the observed deterioration, since the non-forged plain nickel lost about 30% of its tensile strength value , whereas that of the composite has deteriorated by nearly 80% when subjected to this combined thermo-mechanical treatment.

Similarly, the elastic modulus of plain matrix and that of the composite behaved in a very much the way.

Figure 8, on the other hand exhibits the variation of the flexural modulus of plain nickel-matrix and that of the composite before and after forging , it is clear that the modulus of material before forging is greater than that of plain nickel-matrix.

But, when forging as a treatment is applied the flexural modulus is explicitly reduced, and in general these modulus-values seem to decline when the materials are subjected to increasing heat treatment temperature.

Following suite is the behavior of the impact strength of these materials exhibited in comparatively in fig.9, the value of the impact strength of plain nickel matrix does not seem to be affected very much by the heat treatment temperature. Whereas, that of the composites seem to decline in general with increasing heat treatment temperature.
Fig. 1 Fine columnar grains surrounding the carbon fiber with radial direction in Ni-C composite cross section shows.

Fig. 2 The microstructure of Ni-C composite preforging at heat treatment temperature (a) 450°C (b) 550°C (c) 650°C.

Fig. 3 The microstructure of Ni-C composite with three forging passes at heat treatment temperature (a) 450°C (b) 550°C (c) 650°C.

Fig. 4 The tensile (stress-strain) curves for plain nickel heat treated at different heat treatment temperatures.

Fig. 5 The tensile (stress-strain) curves for Ni-C composites treated at different heat treatment temperatures.
temperatures and forged with (a) preforging, (b) 1 forging pass, (c) 3 forging passes.

Fig. 6 The effects of heat treatment temperatures on the ultimate tensile strength of plain nickel and its composite.

Fig. 7 The effects of heat treatment temperatures on the Young’s modulus of plain nickel and its composite.

Fig. 8 The effects of thermomechanical treatment temperatures on the flexural modulus of plain nickel and its composite.

Fig. 9 The effects of heat treatment temperatures on the impact strength of plain nickel and its composite.