ORNL Manufacturing Demonstration Facility
Technical Collaboration **Final Report**

Development of Graphene – Titanium Composite Sheet with Increased Thermal Conductivity using Powder Metallurgy Processing[1]

XG Sciences, Inc.

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Summary
ORNL worked with XG Sciences, Inc. to develop a processing method for producing a composite material incorporating graphene platelets in a titanium matrix with the goal of improving thermal conductivity. Powder metallurgy processing was used to produce consolidated plates of the composite material. However, the thermal conductivity of the plates in the through-thickness direction was not improved by the addition of the graphene platelets.

Background
XG Sciences has developed a proprietary manufacturing process for producing low-cost graphene nanoplatelets (Figure 1). Graphene exhibits a broad range of exceptional properties, including: high strength, high thermal conductivity, and excellent electrical conductivity. Graphene has been shown to have a significant effect on composite properties when it is incorporated as a second phase in a polymer or liquid matrix, even at levels as low as 0.1 wt.%. XG Sciences was interested in exploring the use of graphene platelets in a titanium matrix with the goal of increasing the thermal conductivity for use in plate-type heat exchangers. However, the company had no prior experience in combining graphene with metals. The partnership was created to take advantage of ORNL's past experience in titanium powder metallurgy processing and to jump start XG Sciences entry into metal matrix composites. The goal of the project was to fabricate composite samples and to demonstrate a 50% increase in thermal conductivity.

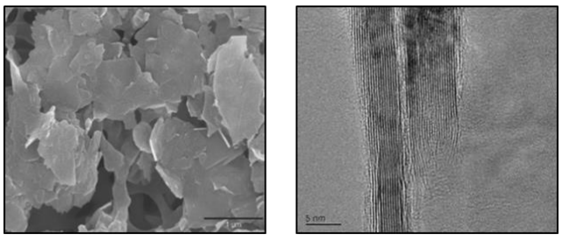

Figure 1. XG Sciences graphene nanoplatelets.

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Technical Results

Initially, a series of test specimens was fabricated by hot pressing blends of titanium powder and graphene. Different grades of graphene and different ratios of graphene-to-titanium were used for these specimens. It was found that when the hot pressing was done at 700°C or higher the graphene would react with the titanium metal to form TiC. At 500°C there was no reaction, but the composite could not be consolidated to a high density. As a consequence of these two factors, the thermal conductivity was reduced for samples containing graphene.

An alternative process was sought to allow consolidation of composites to high density at low temperatures. This was accomplished in a multi-step process. The blended graphene and titanium powder was placed in a vacuum sealed stainless steel can and upset forged at 500°C. The forged composite material then underwent a series of rolling steps at temperatures of 350°C to 500°C, with the shear roll mill at the MDF being used for the lower temperature operations (Figure 2).

Figure 2. MDF isothermal shear rolling mill.

High consolidation density was achieved by this approach due to the severe mechanical strain associated with the processes. However, it was once again found that the through-thickness thermal conductivity of the rolled plates was lower when graphene was present (Figure 3). It is believed that this is due, at least in part, to an induced orientation of the graphene platelets in the plane of the plates. Evidence of incipient micro-scale cracking in the composites was also observed. This would disrupt the propagation of phonons in the material and result in lowering the thermal conductivity.

Impacts

The intent of the development of a graphene/titanium composite plate with improved thermal conductivity was to enable the use of heat exchangers for recovery of thermal energy in corrosive and elevated temperature industrial settings. The results of this collaborative project indicate that more research will be needed to achieve this goal.

Conclusions

This collaborative project has shown that graphene platelets are not stable in titanium at temperatures above 700°C. The graphene will react with the titanium to form TiC. However, it was demonstrated that by processing the composite material using high mechanical strain, fully consolidated plates could be formed at temperatures that are low enough to prevent reaction between the graphene and titanium. Despite this accomplishment, it was found that the processing method introduced microstructural features in the composite that lowered the through thickness thermal conductivity of composite plates. These included orientation of the graphene platelets in the plane of the plate and the formation of microscopic incipient cracks.

XG Sciences is able to control the size, shape, and edge chemistry of their graphene nanoplatelets to modify the effective properties. This could include improved dispersion and passivation of the platelets in a reactive matrix. Although, it may be possible to overcome the challenges related to the orientation of the graphene platelets in the plane of the plate and the formation of microscopic incipient cracks that were observed during the conduct of this project, no additional work is contemplated.

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