Manufacturing Process of NCG carbon fiber and Al_2O_3 Whisker Reinforced 2024 Al MMC by Sqeeze Casting

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ASTRACT

The hybrid reinforcement of nickel coated graphite(NCG) fiber and Al_2O_3 whisker is considered for 2024 aluminum MMC for sqeeze casting. The preform of the hybrid reinforcement is fabricated by the modified vacuum suction technique. The instability of nickel coated layer on the carbon fiber at elevated temperature is examined to be applied for the optimum manufacturing process of MMC. The microstructures and the tensile test properties of the processed MMCs are observed for two kind NCGs - commercially available Cyanamid NCG and electroplated KIMM NCG. The results with respect to the possibility of low cost carbon fiber application on MMCs and the feasibility of the hybridization of the continuous and the discontinuous fiber are suggested for MMCs' application as an automobile material.

Keywords:Hybrid preform, Nickel Coated Graphite, Sqeeze casting, Instable interface, Optimum manufacturing process, Tensile test,

1. Introduction

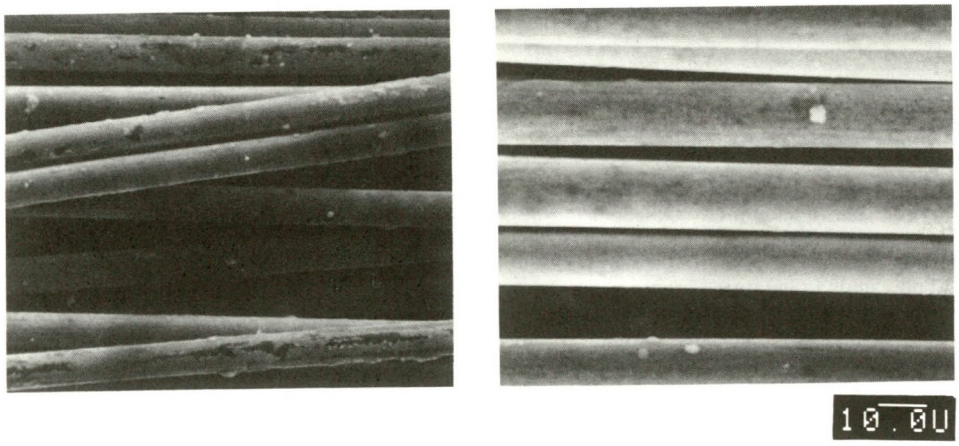
Metal matrix composite(MMC)s are expected and applied for a wide applicable automotive materials with their high specific strength and stiffness at relative high temperatures. These properties are appropriate for the improvement of the rate of fuel consumption as well as light automotive structure[1-4]. However, few problems for commercially feasible productions of MMC, which are pointed out recent few years, are still expensive continuous ceramic fibers, reliable manufacturing process and direct approaching way of MMC on real products. Among these barriers for wide application of MMCs, a substitutivee fiber for expensive continuous ceramic fiber has been studied to reduce the cost of final MMC produts. Even though this low cost substitutive reinforcement fiber, carbon fiber, is helpful in the viewpoint of production cost, there are intrinsic problems of carbon fiber with metallic matrix materials. Carbon fibers have poor wettability and strong chemical reaction to metals. Therefore, carbon fiber coated with metallic layers is being considered as a reinforced material for MMC[5].

In this study, Nickel Coated Graphite(NCG) fiber and ICI Al_2O_3 whisker reinforced 2024 aluminum matrix composite system is investigated to develop the applicability of NCG for MMC. The hybrid preform of NCG fiber and Al_2O_3 whisker is prepared with the modified vacuum suction technique[6] which putting one layer of NCG fiber over the whisker layer repeatedly. The hybrid preform is exposed to the temperature between 300°C to 500°C for proving the instability of nickel layer on the carbon fiber. This result as well as the previous optimum process range of SiC/Al[7] is used for the fabrication of the hybrid fiber reinforced 2024 Al MMC by squeeze casting. Fabricated hybrid fiber reinforced MMCs are observed their microstructure and mechanical properties to show the soundness for a automobile material. These results are compared with the Tae-Kwang uncoated carbon fiber reinforced MMC and the Cyanamid NCG fiber reinforced MMC.

2. Experimental Procedure

2.1. Fiber and Matrix

Reinforcement materials used in this study are two kind of NCG fibers and ICI Al_2O_3 whisker. One NCG fiber is commercially available Cyanamid fiber and the other NCG fiber is laboratory prepared NCG fiber which used Tae-Kwang carbon fiber and coated by KIMM with using elertoplating. Matrix material chosen here is 2024 aluminum. As-received Cyanamid NCG and KIMM NCG are observed for their coated layer. Cyanamid NCGs are appeared more uneven nickel coating layer than KIMM NCGs (Fig.1). This uneven coating layer consequently becomes the source of fracture due to the degradation during the fabrication. Typical mecanical properties of Cyanamid NCG are listed in Table 1.



a) As-received Cyanamid NCG carbon fiber b) As-received KIMM NCG carbon fiber

Fig.1 As-received NCG carbon fibers.

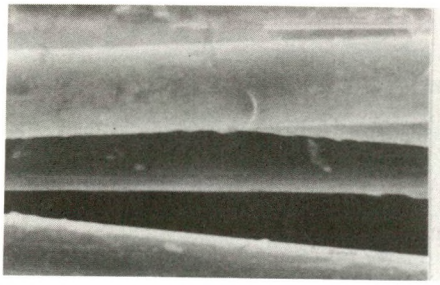
NCG Filament Diametyer	7.6 microns
NCG Fiber Yield	2,000 miles/lb
Specific Gravity	3.0
Nickel by Weight	40%(nominal)
Nickel Purity	99
Tensile Strength	436,000
Tensile Modulus	29,600,000
Electrical Conductivity	0.008 ohms per
Temperature Stability(24hrs)	430°C(800°F)

Table 1. Typical mechanical properties of Cyanamid NCG

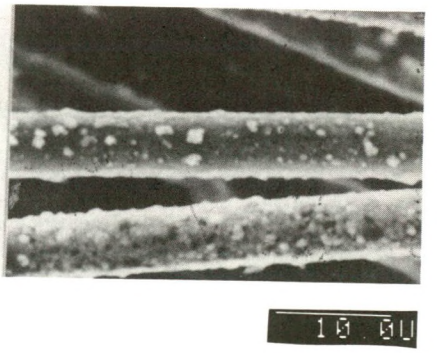
2.2. Hybrid Preform

The hybrid preform of NCG fiber and Al_2O_3 whisker is prepared by the modified vacuum suction technique. In other to obtain the sound hybrid preform, the vacuum pressure and the amount of the binder are controlled. The optimum value of two parameters are found by observing the microstructure of each prepared preform. The adoption of hybridizing continuous and

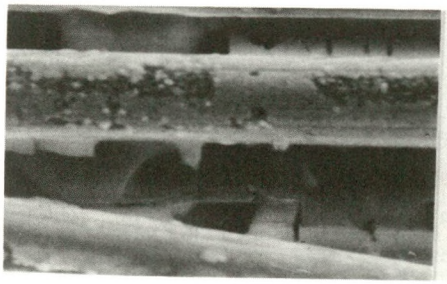
discontinuous fiber is found its reason on shaping near-net for the final product and decreasing the temperature effect on the coated layer. In the hybrid preform prepared, the volume fraction of NCG fiber is 5% and that of Al_2O_3 whisker is 20%. The hybrid preform is exposed to the temperature between 300°C to 500°C for the instability of nickel layer on the carbon fiber. Microstructures of Cyanamid NCG and KIMM NCG both combined with Al_2O_3 whisker at different temperatures are shown in Fig.2 and Fig.3. Up to 300°C, both hybrid preforms exhibit no degradation region in the nickel coated layer. With the increasing exposure temperature, Cyanamid NCG and Al_2O_3 whisker preform exhibits the degradation of nickel layer on uneven nickel coated portion in as-received state one.



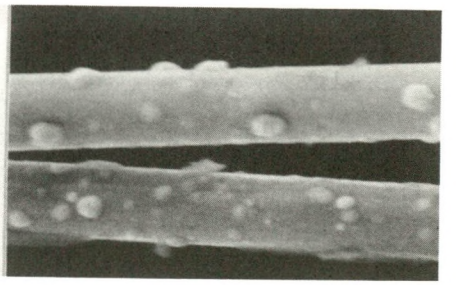
a) 300 °C



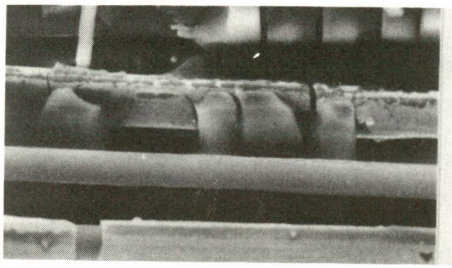
a) 300 °C



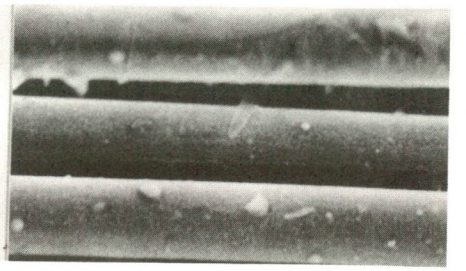
b) 400 °C



b) 400 °C



c) 500 °C



c) 500 °C

Fig. 2 Microstructure of the Cyanamid NCG and Al_2O_3 hybrid perform at different temperature

Fig. 3 Microstructure of the KIMM NCG and Al_2O_3 hybrid perform at different temperature

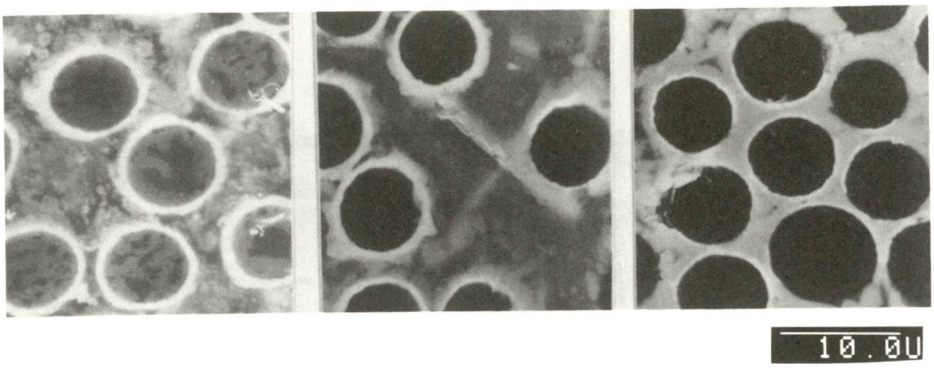
2.3. Manufacturing MMC

On the basis of the result of exposing test and the previous optimum process manufacturing process[7], the preheating temperature of the preform and the melt pouring temperature are determined as 300°C and 800°C. The other processing parameters such as the applied pressure and the holding time in squeeze casting are varied between 10 seconds and 90 seconds, 60 MPa and 100MPa. The optimum processing range is determined by investigating the microstructure at the fiber-matrix interface.

3. Results

3.1. Microstructural Observation

To insure the compatibility between the hybrid reinforcement and the matrix metal, microstructural observations are carried out for fabricated specimens under different processing conditions. One composite system- called A composite here - which consisted of Cyanamid NCG fiber and ICI Al_2O_3 whisker with 2024 Al matrix is observed its and transverse microstructure variation with the applied pressure(Fig.4). It is found that the nickel coated layer is resolved into the matrix with increasing the applied pressure. This result might be explained in the way : nickel coated layer is broken by high applied pressure during the infiltration of the melt into the hybrid preform, the melt is infiltrated into the broken nickel layer, and the nickel layer finally is resolved into the matrix. The mechanism of this broken coated layer into the matrix is dipicted in Fig.5.



a)60 MPa b) 80 MPa c) 100 MPa

Fig. 4 Transverse microstructure of the Cyanamid NCG carbon fiber and Al_2O_3 reinforced 2024 Al matrix composites at different temperature.

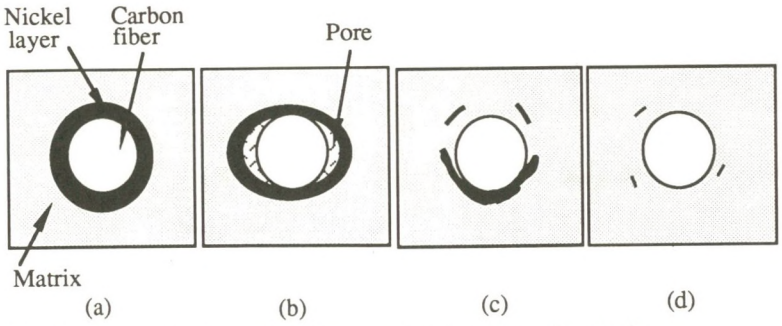
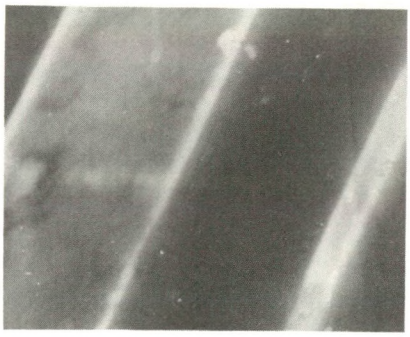
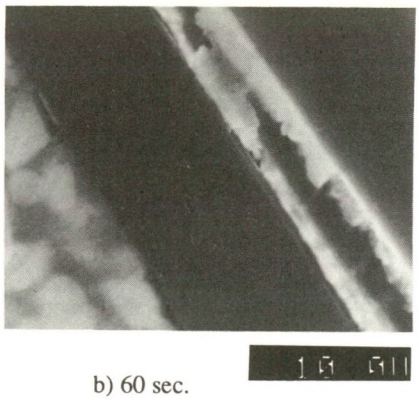


Fig. 5 The mechanism of resolving nickel layers into the matrix.

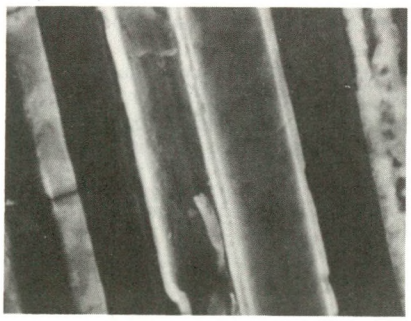
The variation of the microstructure of A composite on the applied pressure hoding time is shown in Fig.6. It is considered that the holding time might influence the thixothropic property of the matrix. Thus, long applied pressure holding time causes the melt flow continuously during the pressure holding. By this melt flow, the nickel coated layer is pressed and debonded from the carbon fiber in the end. This mechanism is expressed in Fig.7. By these microstructural observations, the optimum manufacturing press of Cyanamid NCG fiber and Al_2O_3 whisker reinforced 2024 Al matrix composite is found that the preform preheating temperature is 300°C, the melt pouring temperature 800°C, the applied pressure 60MPa, and the pressure holding time 10seconds.



a) 10 sec.

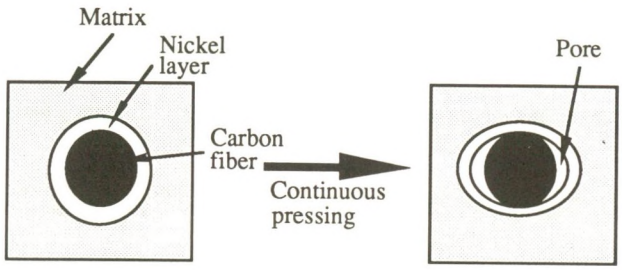


b) 60 sec.



c) 90 sec.

Fig. 6 Longitudinal microstructure of Cyanamid NCG+Al_2O_3/2024

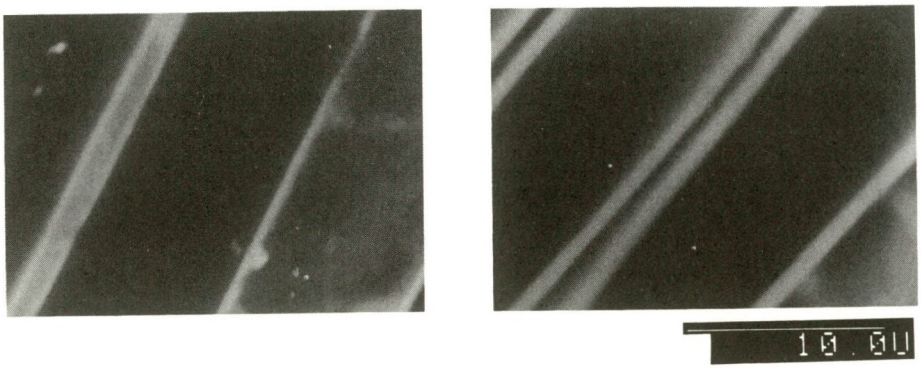


(a) (b)

Fig. 7 Mechanism of debonding nickel layers from the matrix.

With this optimum process, KIMM NCG fiber and ICI Al_2O_3 whisker reinforced 2024 Al matrix composite, called B composite here, is also fabricated and observed its longitudinal

microstructure. The comparision of the microstructure of A and B composite is made in Fig.8. From this comparision, it is to make the statement that better condition of NCG surface - B composite - brings better microstructure of the final composite.



a) Cyanamid NCG+Al_2O_3/2024 Al b) KIMM NCG+Al_2O_3/2024 Al

Fig. 8 Longitudinal microstructure of both Cyanamid NCG reinforced composites and KIMM NCG reinforced composites.

3.2. Mechanical Properties

Tensile tests are conducted on A and B composite specimens. Specimens having the dimension as shown in Fig. 9 are machined with the fibers parallel to the logitudinal direction. Tensile tests are carried out from 25°C to 300°C at a cross-head speed of 0.5mm/min. Ultimate tensile strength of A and B composites prepared by the optimum fabrication conditions are shown in Fig.10. The ultimate tensile strength of B composites at room temperature is 130% higher than B composite. Also, the ultimate tensile strength of B composite is not changed up to 300°C.

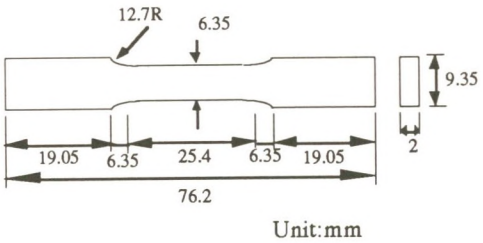


Fig. 9. Dimension of Specimens

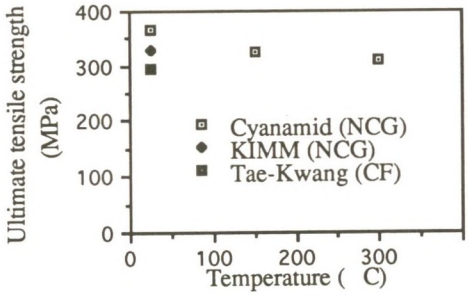
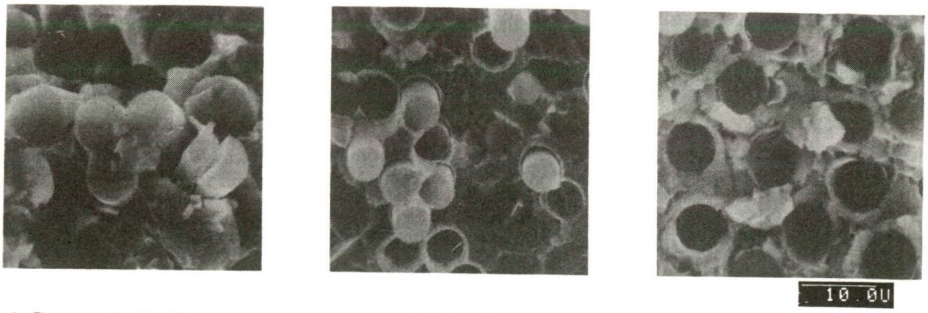


Fig. 10. Ultimate tensile strengths

Fractographical observations of A and B composite at room temperature are made in Fig.11. Fiber pull-out which directly influences the tensile strength is less found in the low tensile strength of A composite than B composite. It can be supposed with the mechanism shown in Fig.12[8]. In Cyanamid NCG reinforced composite, uneven coated nickel layers of the carbon fiber is contacted directly with the melt matrix and produced the carbide - Al_4C_3,Al_4O_4C - [9] on the fiber surface. This pitting phenomena causes the premature longitudinal failure of the fiber due to the local stress concentration[10-11]. In KIMM NCG reinforced composite, the nickel coated layer is contacted with the matrix. Therefore, the nickel coated layer is reacted with the matrix and served as the origin of crack. This crack is propagated into the matrix and captured in the yield zone the nickel

coated layer.

The fractographical observation of B composite at high temperature is also performed and shown in Fig.13. The result is almost same as the phenomena at room temperature. Thus, it supports the mechanism of the fracture in the coated and the uncoated layer of the reinforcement carbon fiber.

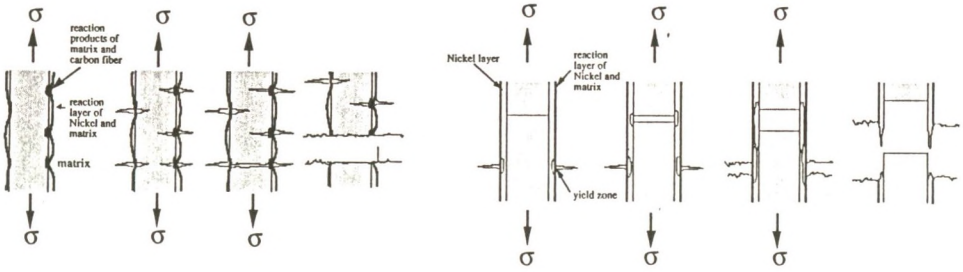


a) Cyanamid NCG reinforced MMC.

b) KIMM NCG reinforced MMC.

c) Tae Kwang CF reinforced MMC.

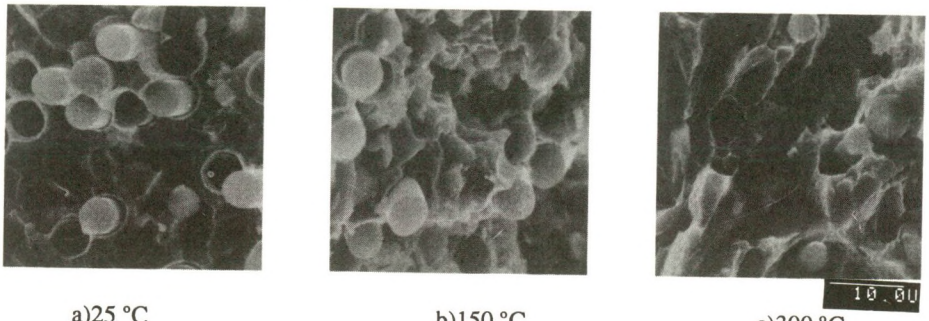
Fig. 11. Fractograph of Cyanamid NCG reinforced MMC, KIMM NCG reinforced MMC and Tae Kwang CF reinforced MMC fabricated by the optimum fabrication conditions at 25 °C



a) Failure mechanisms in Cyanamid NCGreiforced MMC

b) Failure mechanisms in Cyanamid NCG reiforced MMC

Fig. 12. Failure mechanism in Cyanamid NCG reiforced MMC and KIMM NCG reiforced MMC



a)25 °C

b)150 °C

c)300 °C

Fig. 13. Fractograph of KIMM NCG reinforced MMC at elevated temperatures.

4. Conclusion

The effects of the hybridization with discontinuous fiber and continuous nickel coated carbon fiber on the properties of MMCs are examined with respect to the compatibility of the fiber and the mechanical properties. Intermediate conclusions can be made in the followings :

1. The exposure temperature of Cyanamid NCG fiber and KIMM NCG fiber reinforced composite is 300 °C for the stability of the nickel layer on the carbon fiber.
2. Better condition of coating layer on the carbon fiber is bring better microstructure and mechanical property in MMC, and which happened in the electroplated NCG fiber of KIMM compared with Cyanamid NCG.
3. It is shown that the electroplated NCG fiber with Al_2O_3 whisker reinforced MMCs are good enough to meet the automobile application in the sense of mechanical properties and the price compared with the other Al_2O_3 whisker or continuous SiC fiber reinforced composites.

5. References

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