# Mechanical Properties of Interpenetrating Phase Composites using Open-Cell Al foams with Natural Rubber and Polyethylene

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## Abstract

Interpenetrating phase composites (IPCs) were produced by conventional casting process, in vacuum atmosphere, using open-cell Al foams as matrix, and filled with either natural rubber or polyethylene. Mechanical properties of IPCs strongly depends on types of polymeric phases. It is found that the IPCs with polyethylene show an increase in compressive strength as well as failure strain. However, a large decrease of compressive strength is observed in the IPCs with natural rubber, as a result of cracks along the interface between Al foam and the rubber. These cracks are distributed throughout foam structure in the IPCs.

**Keywords :** Interpenetrating phase composite, Aluminium foam, Microstructure, Mechanical properties.

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## Introduction

At present, many materials are being developed to have special properties for which cannot be found in conventional materials, such as metal, ceramic and polymer. The special properties are often obtained from combined properties of different materials. Composite material is a multi-phase material which has resulted in a development of multi-functional properties for more applications. Each phase exhibits good properties of its own phase and get better properties from other phases reinforcement. This is attractive to automotive industry which needs a material with good mechanical properties and light weight.

Metallic foams are a light-weight metal which composes of high porosity, approximately 70-95 vol.%. They have excellent combined properties, such as high specific strength, low density, large energy absorption capacity and high service temperature.[1, 2] They can be classified into two types, according to their pore structures; open-cell and closed-cell foams. The pores of open-cell foam are interconnected, and that fluid can pass through, while those of the closed-cell foam are not interconnected. Open-cell foams are preferential for functional applications, such as sound insulators, heat exchanger and filters.[3, 4] Nevertheless, the use of open-cell foams is only in low stress applications.[5-7]

Interpenetrating phase composite (IPC) is a new type of composite materials. It has co-continuous 3-D network of interconnecting phases. Because of this, the continuous phases can yield maximum contribution to their own properties. Moreover, IPC material has isotropic mechanical properties, as a result of its isotropic structure. The mechanical properties of IPC strongly depend on continuous matrix and interpenetrating materials. There produced by using open-cell structure of metal foam which and filling polymer materials. It has been reported that the mechanical properties of ICPs made with metallic foams can be significantly enhanced.[8-14] The increase of strength and energy absorption is resulted from the presence of interpenetrating phases. However, more investigation in the microstructure and properties of IPCs is needed, in order to understand the behavior of IPCs.

The objective of present research work is to produce IPC materials, by using open-cell aluminium (Al) foam, as matrix phase, and investigate their interconnecting structures and mechanical properties, relative to types of polymeric materials. The fabrication of Al foams is implemented using investment casting method. Two different polymers; natural rubber and polyethylene, are selected, in order to examine the effect of elasticity to IPCs.

## Materials and Experimental Procedures

The open-cell Al foams were produced using the investment casting process with assisted pressure. The cellular pattern was obtained from a replication of polyurethane (PU) foam structure, with pore size of 12 ppi. Firstly, the PU foam was invested with a plaster into a 120 mm diameter cylindrical mold,



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followed by sintering in a resistance furnace at 650°C for 8 h, in order to remove the PU foam and strengthen the mold. Preparation of Al foams was performed by melting Al billets at 1000°C and infiltrating the molten Al into the plaster mold, with nitrogen gas pressure of 100 psi, using Old Moon BU 450 vacuum system casting machine. The casted Al foams were then cooled in air, followed by rupturing the plaster mold by quenching in water. A water jet stream is also used to remove plaster debris that adhere to the foam surface. The IPC samples were prepared by casting process of polymeric materials ; natural rubber (NR) and polyethylene (PE), into interpenetrating porosity of Al foams. The samples were then cured in vacuum atmosphere.

Characterization of IPC samples was prepared by sectioning the samples into a rectangular rod with the dimension of 10×10×10 mm, using a precision cutting machine (Struers Accutom-5), followed by light grinding. Both macrostructure and microstructure of samples were examined by JSM-6400 JEOL scanning electron microscope (SEM). Mechanical testing was performed using a universal testing machine (Shimadzu EZ-S) with 50 N load cell and constant cross-head speed of 1 mm/min, in order to determine compressive characteristic and yield strength. The dimension of compressive foam specimens were 25x30x50 mm.

## Results and Discussion

Figure 1 presents the morphology of open-cell Al foam specimen. The foam structure is a replication of the cellular structure of PU foam. No major defects, such as crack or unfilled struts, are observed. The density of Al foam is approximately 0.30 g/cm$^3$. Using Archimedes' principle, the density of NR and PE of 6.95 and 5.85 g/cm$^3$ can be determined, respectively. The density of IPCs filled with NR and PE can also be calculated using the rule of mixture, yielding to 6.10 and 6.15 g/cm$^3$, respectively.


**Figure 1.** Al foam specimen.

Microstructures of IPCs specimens, filled with NR and PE, are shown in Figure 2. It is clear that both NR and PE can infiltrate and fill up the interconnected pores of Al foams. However, the interfacial bonding between these polymeric materials and Al foams are different. A disintegration of interface between NR and Al foam is observed, resulting in a large crack along the interface. It is likely that the crack was formed as a consequence of large contraction in NR, relative to that of Al foam, due to a large mismatch of the coefficient of thermal expansion (CTE) between Al matrix and NR. The CTE of Al and NR are reported to be about 23 and 650 ppm/°C, respectively.[15,16] However, this is not the case of PE with Al foam. It can be seen that no segregation of interface is detected. The CTE of PE is approximately 13 ppm/°C(17) and closer to that of Al, yielding to intact interface.

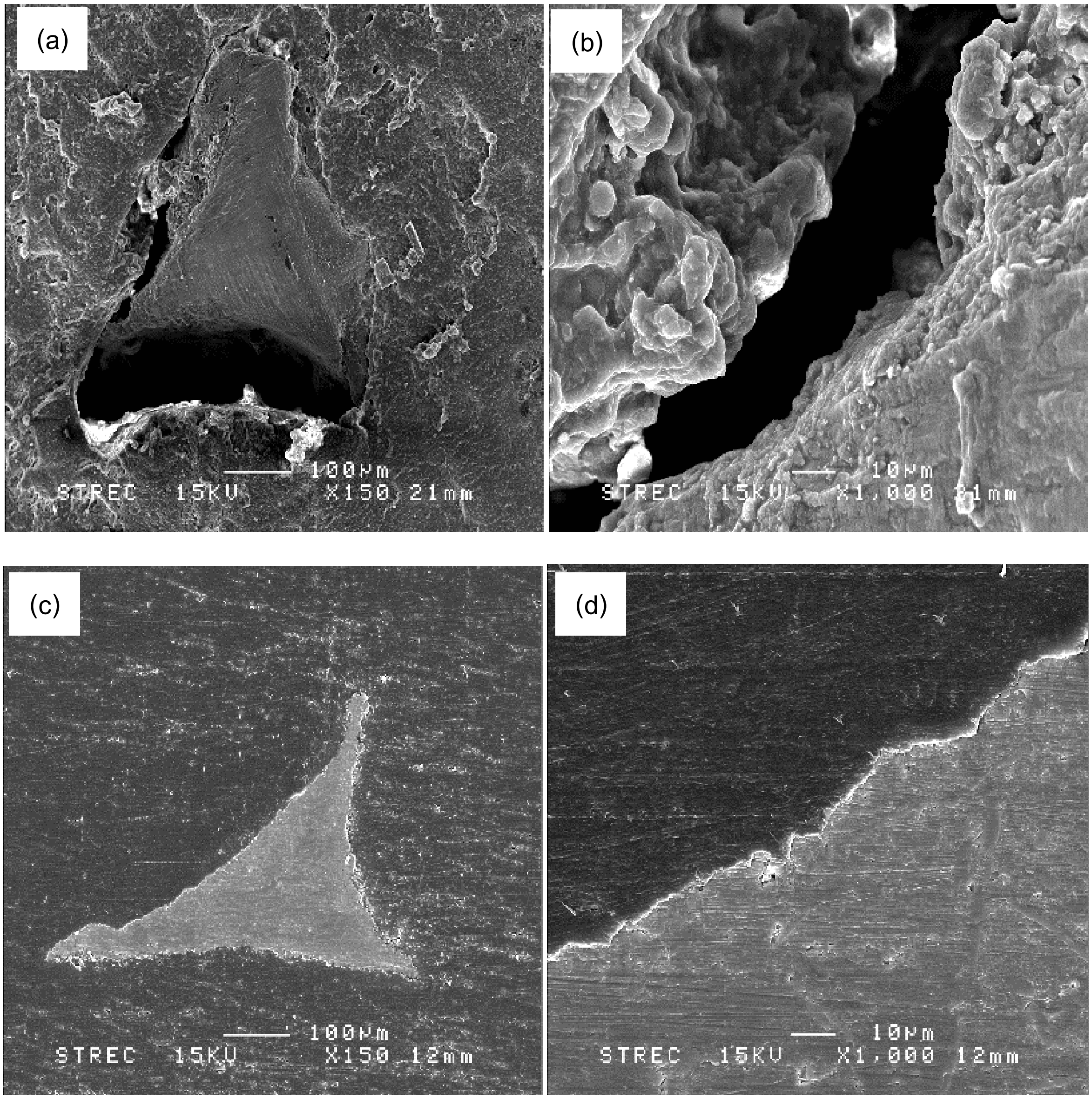


**Figure2.** SEM micrographs showingmicrostructure of IPC specimens, filled with (a) natural rubber and (c) polyethylene. Higher magnification images of the IPC specimens are presented in (b) and (d).

Figure 3 presents the compressive mechanical behavior of IPCs specimens with NR and PE. It is clear that the compressive behavior of IPCs with different types of polymer is different. The IPCs with NR has a very large compressive strain, due to a large elasticity in NR, compared with the IPCs with PE. An increase of compressive stress in IPCs is seen only with the specimen filled with PE. The maximum compressive stress of IPC is increased to 5.85 MPa and the failure strain is extended to approximately 40% strain, indicating a significant improvement of mechanical properties. The enhancement of compressive stress-strain curve suggests that energy absorption of the IPCs will also be increased.

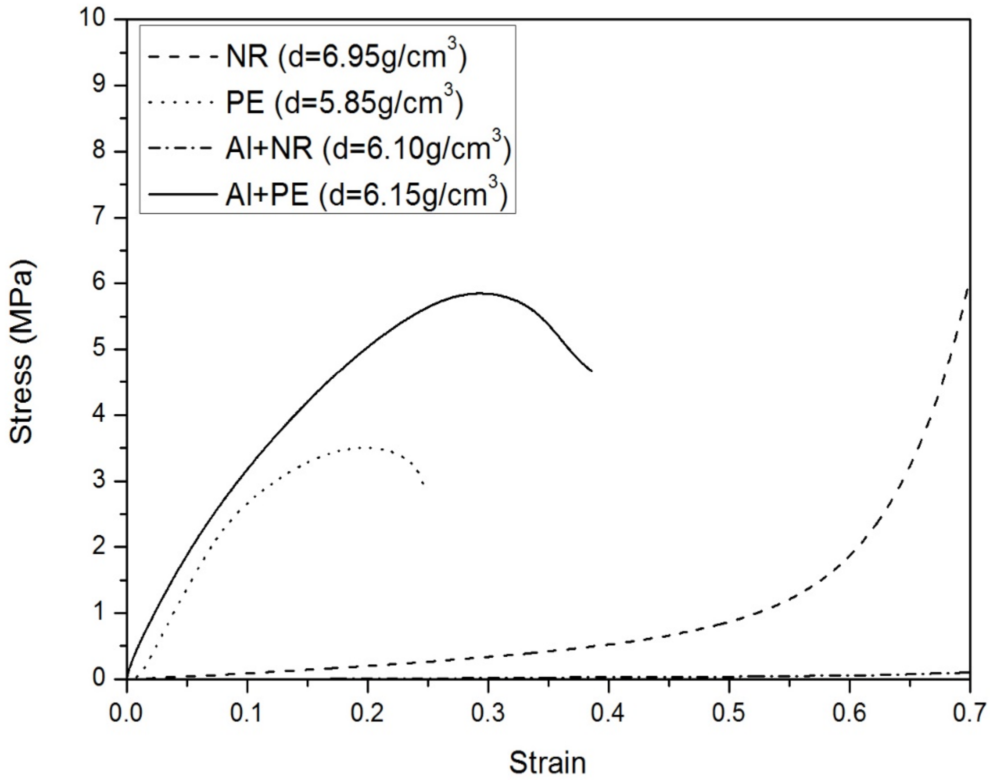


**Figure 3.** Compressive mechanical behavior of IPC specimens filled with natural rubber and polyethylene.

In contrast, the use of NR with IPCs resulted in a large decrease of compressive stress. The deterioration of mechanical properties is resulted from the detachment of interface between Al foam and NR, creating defects along the interface. In addition, these defects are distributed throughout foam structure in the IPCs, resulting in low resistance of composite structure to compression. As a result, it is necessary to produce IPCs with strong interfacial bonding of co-continuous phases.

## Conclusions

The IPC materials, made using open-cell Al foams with either natural rubber or polyethylene, have been successfully manufactured through casting process in vacuum atmosphere. The compressive behavior of IPCs was different, depending on types of polymeric phases. An improvement of compressive strength was found in the IPCs with PE. On the other hand, the IPCs with NR exhibited a large decrease of compressive strength, due to the presence of crack along the interface between NR and Al foam. The crack was formed as a result of large mismatch of the coefficient of thermal expansion between Al and NR.

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