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Review of various studies concerning investigation of mechanical properties of Interpenetrating Metal/Ceramic Composites

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***Abstract*-This paper discuss findings of the various studies concerning investigation of mechanical properties of Interpenetrating Metal/Ceramic Composites. Considering IPC (Interpenetrating) MMC there is percolation of ceramic and metallic phases. This happens in 3D. As compare to fibre-reinforced and particle MMCs, there is little exploration of IPCs. This is because phase architecture is not simple. It is complex for IPCs. Hence, it is difficult to study mechanics of IPC composites. There is some published work available in this regard. Recently, many authors in their research papers have mentioned about mechanical properties considering two IPCs. It helped to develop significant knowledge base composite material's mechanics. To understand mechanical properties of composites numerical simulation is carried out. Here, relevant model concerning composite material is considered. There is not enough literature concerning such models. Porous material's mechanical behavior is affected by three-dimensional geometry. Structure of cellular material is complex. Hence, in context of cellular material, it is difficult to establish relationship between properties and structure. Numerical model can be built either by CAD software or computer tomography images. There is a discussion about new class of ceramic/metal composites. Freeze casting technique is also discussed. Literature concerning semi-solid forming manufacturing technology, composites of resin-metal interpenetrating phase, production of hydrogel using interpenetrating network etc. has been mentioned in the paper.**

***Keywords*: Mechanical properties, Interpenetrating, Metal, Ceramic, Composites, numerical simulation**

I. Introduction

Ceramic reinforced metals are characterized by low thermal expansion, high elastic modulus, tribological properties, high strength etc. There is emphasis on fiber re-inforced/particle composite. There is non-continuity in ceramic phase. Over the last few decades, MMCs (Metal Matrix Composites) were explored. Due to this there is cost reduction in processing. There is improvement in material properties. Because of this some useful and better commercial application were generated. In case of some light metals i.e. magnesium and aluminum, phase is included (discussed by Lloyd, 1994 [1] and Clyne, 1993 [2]). This is done to have reduction in thermal expansion coefficient, higher wear resistance, hardness, stiffness, strength etc. Mattern et al., 2004 studied that how resulting composite properties were affected by properties of preform microstructures. He discussed aluminum-alumina composites. Here, in overall microstructure there is interpenetration of two phases. Pore forming agents that are sacrificial were used to generate ceramic preform. Process applied was direct squeeze-casting. In this case, interpenetrating microstructures were generated on micrepore and macropore scale.

Roy et al. 2014 [3], studied that how mechanical properties were affected by phase architecture. Here, two MMCs those are interpenetrating were considered. Ceramic and metallic phases are same. Phase contents are also same. For one composite, a preform that is infiltrating freeze-cast alumina was used for fabrication purpose. For other composites, infiltrating open porous alumina foam was used. Tests were done to find out under compression internal load transfer, under compression behavior of plastic-elastic flow and elastic constants those are three logitudnals. Roy et al. 2014 [3], found that mechanical properties of composites are significantly affected by phase morphology. In case of freeze-cast MMC, considering freezing direction, highest compressive strength and highest stiffness could be seen. There is more isotropic behavior in case of MMC that is foam based.

Considering ceramic reinforcement of Metal matrix composites there is a significant combination of wear, fatigue and creep resistance stiffness and strength. Density is less here (Chawla and Chawla, 2006 [4]). MMCs play significant role in applications those are weight critical for example automobile and aircraft industries. Considering IPC (Interpenetrating) MMC there is percolation of ceramic and metallic phases. This happens in 3D. As compare to fibre-reinforced and particle MMCs, there is little exploration of IPCs. This is because phase architecture is not simple. It is complex for IPCs. Hence, it is difficult to study mechanics of IPC composites. Roy et al., 2014 [3], carried out load transfer analysis. It refers to Alumina in the composite. Load fraction is close to 90 percent of applied stress. Considering MMC that is foam based, it is close to 50 percent.

Piat et al., 2010 [5] discussed development of new class of ceramic/metal composites. Freeze-casting technique was used. Using this technique pore structure was generated. This pore structure was related to preform that porous ceramic. Here, domains concerning composite microstructure is similar to lamellar.

Piat et al., 2010 [5] attempted to identify appropriate micromechanical model. This was done for mechanical properties deduction from domains those are single. First of all polarized light microscopic micrograph concerning specimen cross section was considered. Then statistical analysis was carried out. Domains having similar lamellae were identified/measured.

Schomer, and Liewald, 2019, [6] discussed structural characteristics concerning ceramic/metal IPC. Here, manufacturing technology of semi-solid forming was used. Yao et al., 2018, [7] discussed energy absorption and anisotropic compressive properties concerning composites of resin-metal interpenetrating phase. Park et al., 2019, [8] described production of hydrogel using interpenetrating network (IPN). As a composite, hydrogel is strong.

Fig. 1 shows plot concerning two MMC type's stress-strain (Compressive) after Roy et al., 2014 [3].

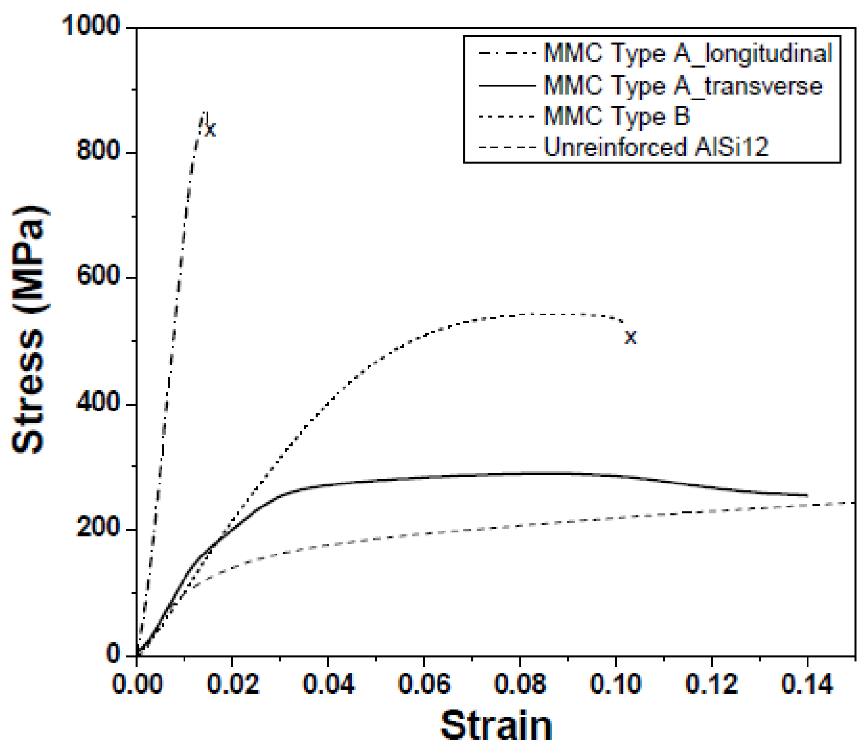

Fig. 1 Plot concerning two MMC type's stress-strain (Compressive) (After Roy et al., 2014 [3]).

Fig. 2 shows concerning two MMC types, Microstrain evolution of solid solution phases of aluminum and alumina (After Roy et al., 2014 [3]).

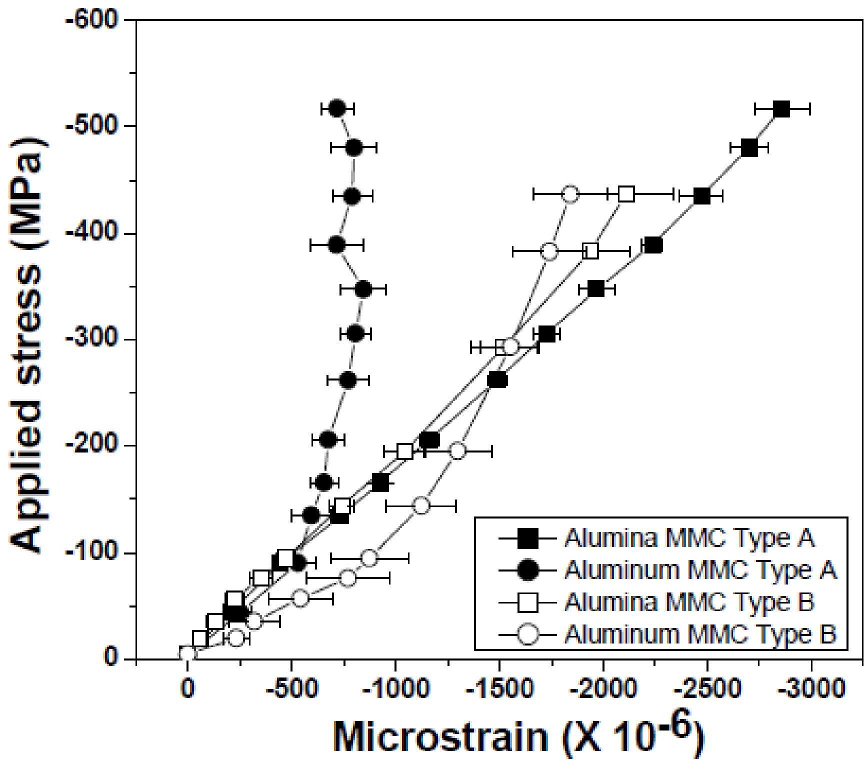

Figure. 2 concerning two MMC types, Microstrain evolution of solid solution phases of aluminum and alumina (After Roy et al., 2014 [3]).

Fig. 3 shows estimated load fraction concerning solid solution phases of aluminum and alumina (After Roy et al., 2014 [3]).

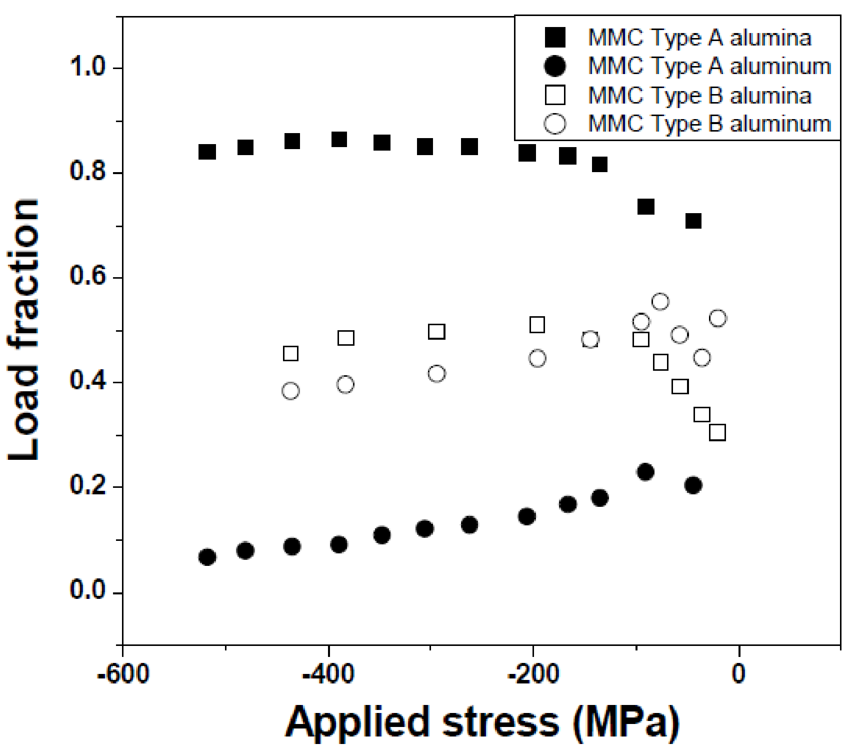

Figure. 3 Estimated load fraction concerning solid solution phases of aluminum and alumina (After Roy et al., 2014 [3]).

Fig. 4 provides pressure and infiltration time relationship (After Matterna et al., 2004 [9]).

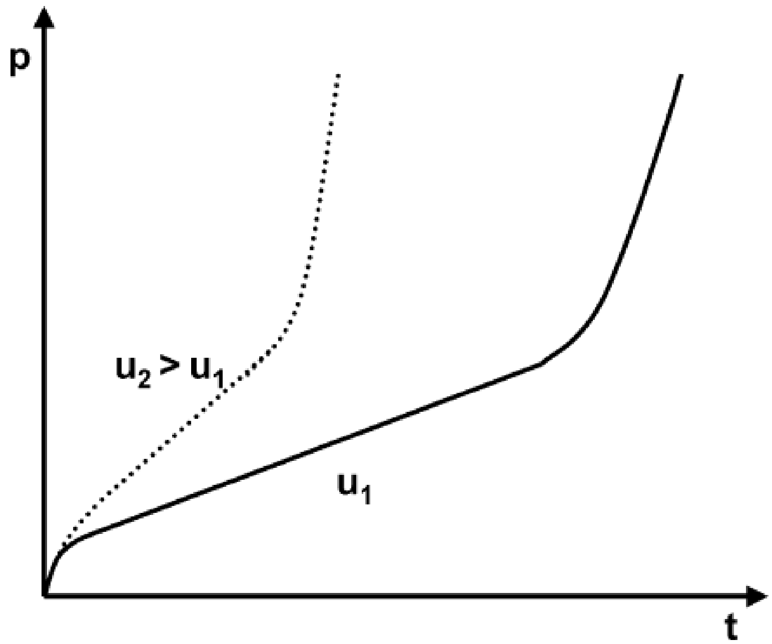

Figure. 4 Considering two melt velocities, pressure increase overview in context of squeeze casting (After Matterna et al., 2004 [9]).

In Fig. 5, assumption is that preform pores are cylindrical (After Matterna et al., 2004 [5]).

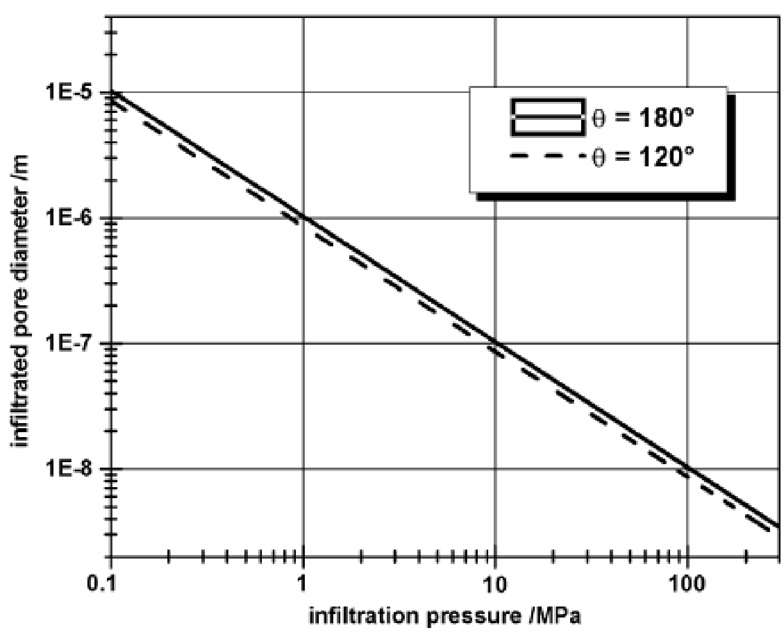

Fig. 5 Infiltrated pore diameter and infiltration pressure relationship (After Matterna et al., 2004 [9]).

The influence of sintering temperature variation may be viewed in Fig. 6 A and B (After Matterna et al., 2004 [9]).

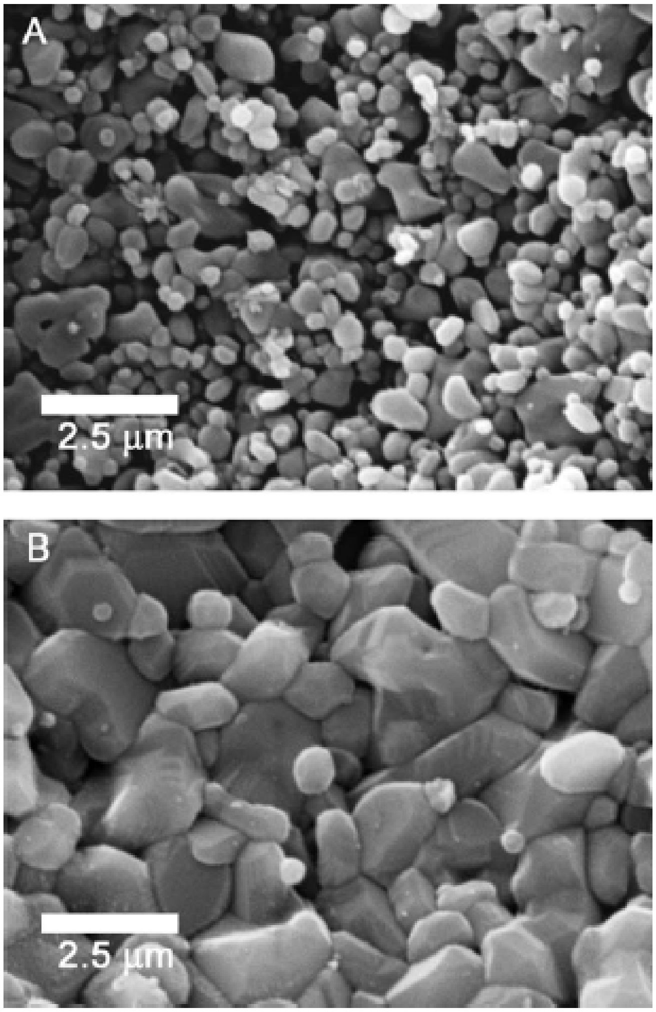

Fig. 6 A Microporous Structure with small grains – 13000 C sintering temperature ((After Matterna et al., 2004 [9]).

Fig. 6 B Dense Structure in large grains - 15000 C sintering temperature (After Matterna et al., 2004 [9]).

On the basis of maize starch, preform microstructure is shown in Fig. 7 (After Matterna et al., 2004 [9]).

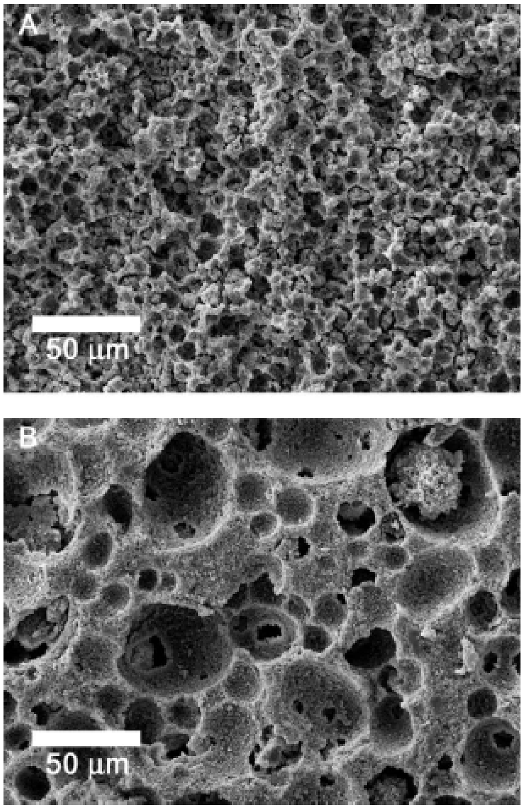

Fig. 7 A Maize starch based preform microstructure (After Matterna et al., 2004 [9]).

Fig. 7 B Potato starch based preform microstructure (After Matterna et al., 2004 [9]).

Nowak et al., 2013 [10] discussed finite element model. Mechanical properties of open cell ceramic foam were explored using this model for example Young's modulus. Computer tomography images were used in context of real foam specimen to get discretization of finite element. 3D geometry was created. Ortega's experimental results were compared with that of Nowak et al., 2013 [10]. Here, experimental results and numerical results match with each other. Considering ceramic foam, it seems that Young's modulus is dependent on finite element mesh density. Real foam topology may be captured by using special script concerning CAD software. Unit cell model-based method are also utilized.

II. INTERPENETRATING MICROSTRUCTURES PROCESSING

Earlier high processing cost and less material ductility were the problematic areas. Recent commercial applications as well as are related to fibre reinforcements and particle. Initially a ceramic body is generated by non-reactive methods. It consists of open porosity network that is continuous. Then a metal melt infiltrate it. In order to fill the pores, an external pressure is required. This is because many metal melts have non-wetting nature. This information is useful for fabrication of preforms. They are able to meet the need of various applications.

III. PORE FORMING AGENTS

To have ceramic parts those are porous, this is a very flexible method. Different PFAs (Pore Forming Agents) were discussed by various workers i.e. carbon fibers15 (Lange et al., 1990 [11]) and flakes (Xu and Chung, 1998 [12]), wax (Dro¨ schel and Grundlegende, 1998 [13]), starch (Corbin and Apte, 1999 [14]), (Galassi, et al., 2002 [15]) suspension PVC (Lopes and Segadaes, 1996 [16]) and polyethylene (Corbin and Apte, 1999 [14]). Here, porosity placement range is 0 - 75%. Within this range it can be controlled as per the added PFA amount.

IV FEM (FINITE ELEMENT MODEL)

RVE (Representative Volume Element) size is modified (Nowak et al., 2013 [10]). RVE is generated using a cube with various sides. Considering each RVE, for top and bottom faces, boundary conditions were applied. Bottom face degree of freedom was locked. To the top face vertical displacement of magnitude was applied. It was one percent of foam height. There was assumption that cell wall material is isotropic. Eight core PC was used to compute Finite Element Model simulation.

V DISCUSSION

This paper summarizes the present status of investigation of mechanical properties of Interpenetrating Metal/Ceramic Composites. Many attempts have been made to study influence of RVE size, type and finite element size on Young's Modulus. Once preform thickness is fully penetrated, pressure is increased significantly. This happens along with micropore filings and compression. When dynamic pressure is low, there are micropores those are not infiltrated. Those micropores are also filled once preform thickness is fully penetrated. Mechanical properties are affected very little by remaining porosity. New ceramic/metal class has been described. There is discussion about Freeze casting technique, semi-solid forming manufacturing technology, production of hydrogel using interpenetrating network and composites of resin-metal interpenetrating phase.

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