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Sintered Density and Porosity of Al-15wt% Pb/Fly-ash Metal Matrix Composites

[1]SEELAM PICHI REDDY, [2]BOLLA RAMANA AND [3]A. CHENNAKESAVA REDDY

[1]*Department of Mechanical Engineering, L.B.Reddy College of Engineering, Mylavaram, A.P.*
[2]*Vikas College of Engineering and Technology, Nunna, Vijayawada, A.P*
[3]*Department of Mechanical Engineering, JNTUH College of Engineering, Hyderabad, A.P*

ABSTRACT

Al-15wt% Pb/fly-ash powder mixtures containing 0 to 20wt% fly-ash were prepared. These were compacted at pressures ranging from 200 to 400MPa by single action die compaction processes. The obtained compacts were sintered in the temperature range of 500 to 590 °C in an argon gas atmosphere. The sintering time was kept as 45minutes. Sintered density and porosity of the compacts were determined as a function of compaction pressure, wt% of fly-ash and sintering temperature. It was observed that the sintered density increased with the increase in compaction pressure and decreased with the increase in wt% of fly-ash. The sintered porosity decreased with the increase in compaction pressure and increased with the increase in wt% fly-ash. The change in the sintered density and porosity is marginal in the temperature range of 500 to 560 °C.

Keywords: Fly-ash, Metal Matrix Composites, Sintering

1. INTRODUCTION

In the last few decades, the use of aluminum (Al) -base alloys as bearing material has increased considerably because of their light weight, high corrosion resistance, good friction and wear resistance. In these alloys metals like lead, tin, indium or cadmium with low melting points are dispersed to work as solid lubricants. Among these metallic additions both tin (Sn) and lead (Pb) are widely used. When compared to Sn, Pb has lower modulus of elasticity, hardness, cost and offer better interfacial film of lubrication [1-6]. It has been reported that ten percent is the minimum acceptable Pb content of an Al alloy if bearings of Pb-Al are to be operated without an over lay under very thin film conditions [7]. From the powder metallurgical characteristics of Al-Pb composites, it was proved that Al -15% Pb composites have minimum spring back, maximum green hardness and strength [8]. Hence 15wt% Pb is added to Al.

Fly-ash is a particulate waste material formed as a result of combustion of coal in thermal power stations. Annually, millions of tons of fly-ash is generated by thermal power stations and most of it is unused and land filled presenting disposal problems. Attempts are being made world wide to utilize this fly-ash as a filler material in metal matrix composites. Fly-ash has been successfully dispersed into cast and wrought Al alloys to make Al alloy fly-ash composites. These Al/fly-ash composites have low density and adequate properties for several industrial applications. The addition of fly-ash to Al decreases the energy content, material content, cost, weight, coefficient of thermal expansion and increases hardness, wear, seizure resistance and stiffness [9,10]. These properties are desirable in materials for automotive applications. Hence fly-ash has been chosen as a filler material to Al -15wt% Pb material.

Production of Al-Pb/fly-ash composites by casting techniques is likely to result in non uniform structure because of wide immiscibility gap between Al and Pb and also large differences in densities of Al, Pb and fly-ash materials. Hence, powder metallurgy technique has been chosen as the manufacturing method for the production of Al-Pb/fly-ash metal matrix composites. The powder metallurgy technique is capable of producing certain components with the uniform distribution of particles in the metal matrix composites.

Leaded-aluminum alloys using powder rolling of the pre alloyed powders were produced by Mackay [4]. Aluminum-17.5% Pb alloys were produced by Gopinath using the conventional powder metallurgical techniques [6]. The compacting and sintering characteristics of Al-Pb powder mixtures were reported by Nath et al [11,12]. Aluminum fly-ash particulate composites by powder metallurgy technique were prepared by R. Q. Guo *et al.* [13,14]. The compacting characteristics of Al-15wt% Pb/fly-ash metal matrix composites were reported [15] and the present paper discusses the sintered density and porosity of Al-15wt% Pb/fly-ash composites.

2. EXPERIMENTAL DETAILS

The materials used in the present investigation were powders of Al, Pb and fly-ash. The Al powder was procured from M/s S. D. Fine Chemicals Limited, Mumbai-India and Pb powder was procured from M/s Lobo Chem, Mumbai-India. Fly-ash was collected from Dr. Narla Tata Rao Thermal Power Station, Ibrahimpatnam, Krishna District, Andhra Pradesh, India. Powder mixtures containing Al-15wt% Pb with 0, 5, 10, 15 and 20wt% fly-ash were prepared and blended in a suitable blender. These powder mixtures were compacted at 200, 300 and 400MPa compaction pressure in a steel die into pellets of 9mm diameter and 9mm lengths using single action die. Silicone spray was used as die wall lubricant. Sintering was done at 500, 530, 560 and 590 °C in an argon atmosphere for duration of 45minutes. Sintered density and porosity of the compacts were evaluated as a function of sintering temperature and compaction pressure.

3. RESULTS AND DISCUSSIONS

The sintered density and porosity of the prepared composites were evaluated and the effects of compaction pressure, wt% fly-ash and sintering temperature on these composites were discussed.

3.1. Sintered Density

Figs. 1 to 4 show the effect of compaction pressure on sintered density for Al-15wt% Pb/fly-ash composites sintered at 500, 530, 560 and 590 °C. The sintered density increases with the increase in compaction pressure. This increased sintered density with the increase in compaction pressure can be explained from better packing and closing of voids present in the green briquettes. With an increase in compaction pressure the metallic particles (both Al and Pb) are plastically deformed and with closer packing the contact areas between the particles are increased which facilitates rapid diffusion and neck growth. The shrinkage of voids and densifications occurs by diffusion of vacancies. This can be clearly observed from the microstructures shown in Figs. 5 to 7 for Al-15wt% Pb/5wt% fly-ash composite compacted at 200, 300 and 400MPa and sintered at 500 °C.

The effect of fly-ash content on sintered density is shown in Figs. 8 to 11. It is observed that, with the increase in fly-ash content the sintered density decreases. This is due to lower density of fly-ash compared to that of Al and Pb.

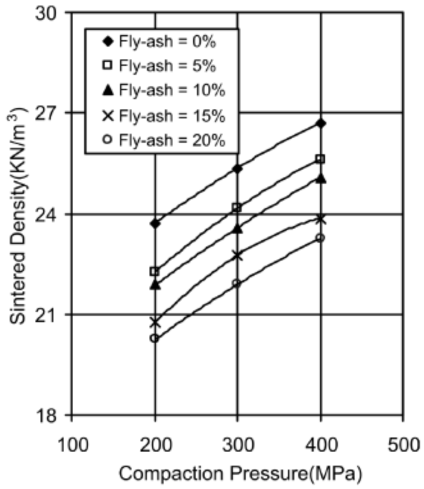

Figure 1: Effect of Compaction Pressure on Sintered Density for Al-15wt% Pb with 0 to 20wt% Fly Ash Sintered at 500 °C

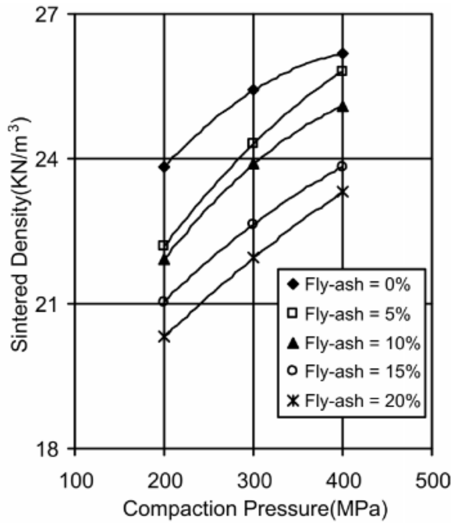

Figure 2: Effect of Compaction Pressure on Sintered Density for Al-15wt% Pb with 0 to 20wt% Fly Ash Sintered at 530 °C

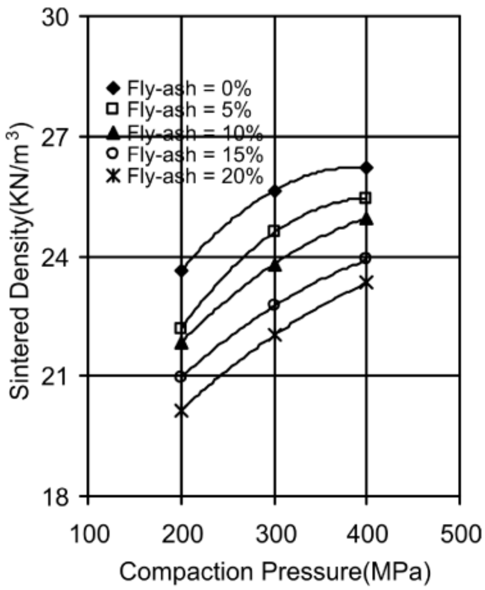

Figure 3: Effect of Compaction Pressure on Sintered Density for Al-15wt% Pb with 0 to 20wt% Fly Ash Sintered at 560 °C

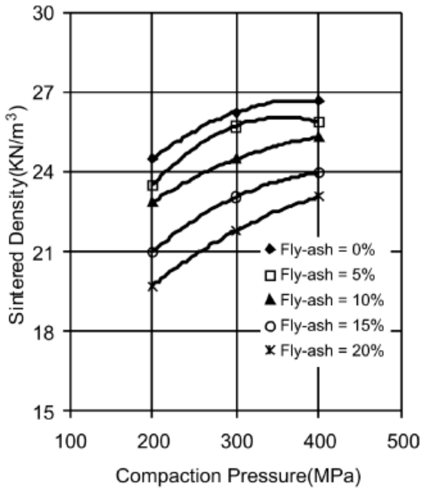

Figure 4: Effect of Compaction Pressure on Sintered Density for Al-15wt% Pb with 0 to 20wt% Fly Ash Sintered at 590 °C

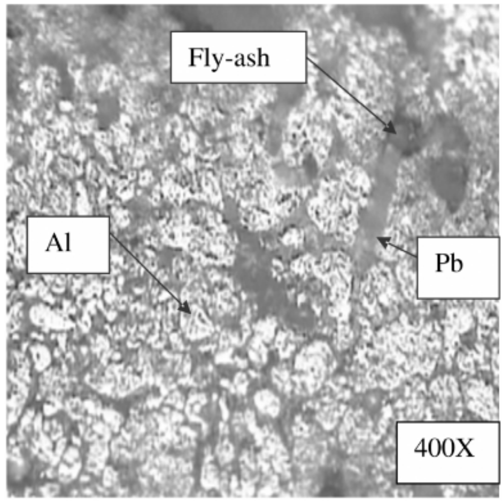

Figure 7: Microphotograph of Al-15wt% Pb/5wt% Fly-ash Composite Compacted at 400MPa and Sintered at 500 °C

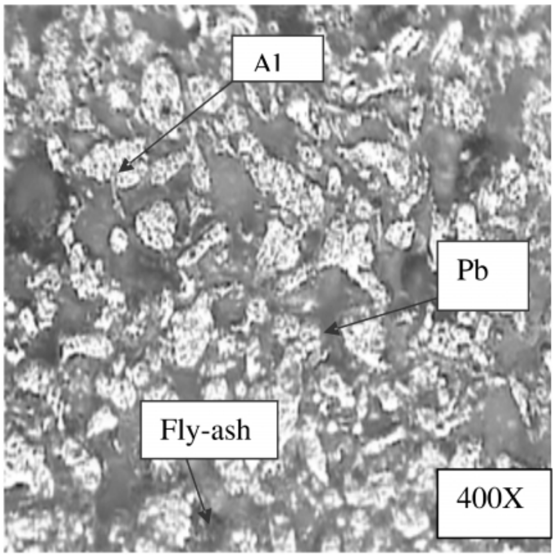

Figure 5: Microphotograph of Al-15wt% Pb/5wt% Fly-ash Composite Compacted at 200MPa and Sintered at 500 °C

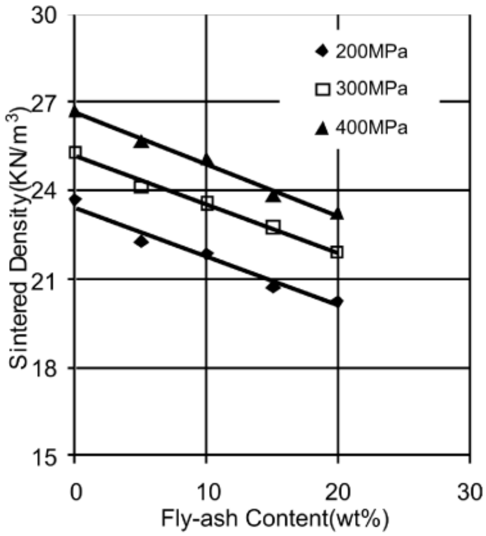

Figure 8: Effect of Fly-ash Content on Sintered Density for Al-15wt% Pb/fly-ash Composites Sintered at 500 °C

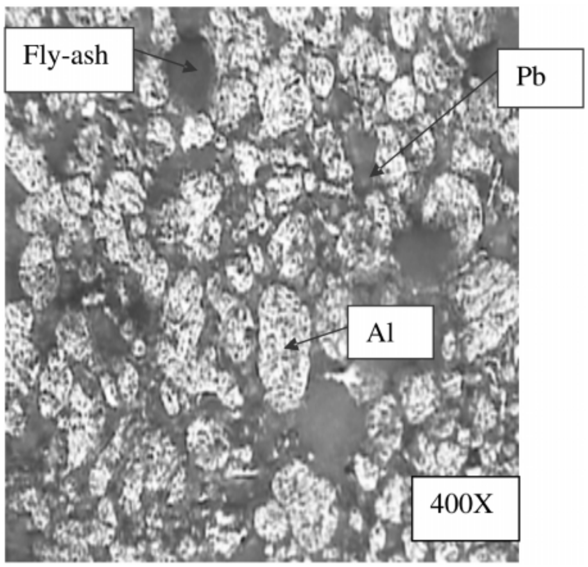

Figure 6: Microphotograph of Al-15wt% Pb/5wt% Fly-ash Composite Compacted at 300MPa and Sintered at 500 °C

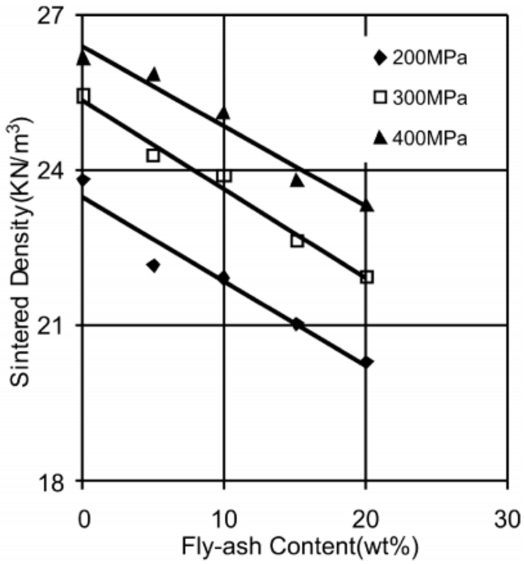

Figure 9: Effect of Fly-ash Content on Sintered Density for Al-15wt% Pb/fly-ash Composites Sintered at 530 °C

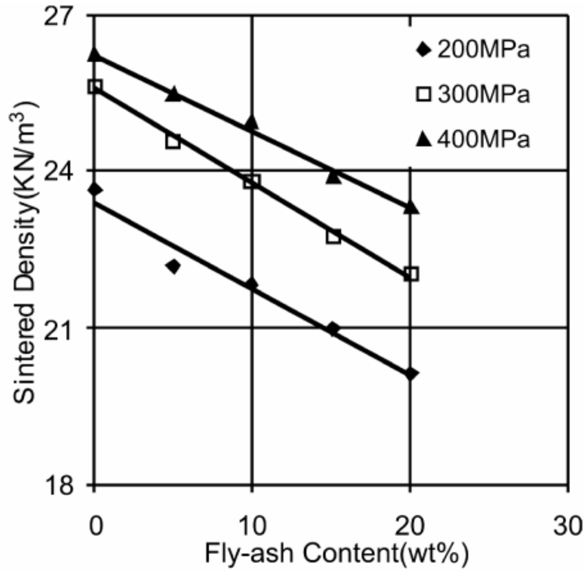

Figure 10: Effect of Fly-ash Content on Sintered Density for Al-15wt% Pb/fly-ash Composites Sintered at 560 °C

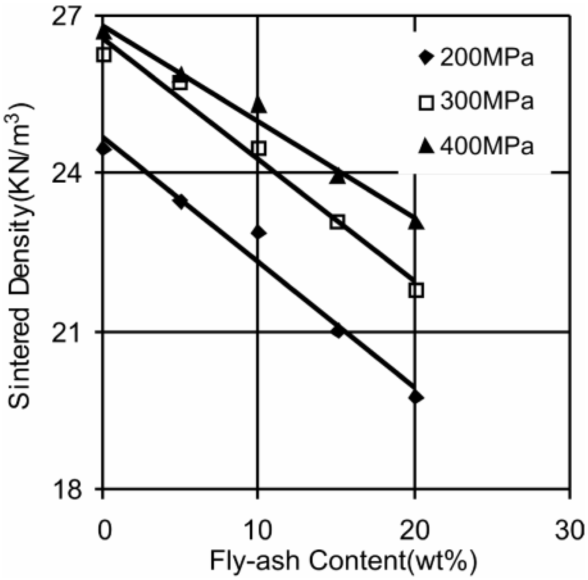

Figure 11: Effect of Fly-ash Content on Sintered Density for Al-15wt% Pb/fly-ash Composites Sintered at 590 °C

Figs. 12 to 14 show the effect of sintered density as a function of sintering temperature for Al-15wt% Pb/fly-ash composites. It is observed that, at a particular compaction pressure, the change in sintered density is marginal in the temperature range of 500 to 560 °C. Beyond 560 °C, a small increase in density is noticed for Al-15wt% Pb/0 to 10wt% fly-ash composites. Negligible change in the density is observed in the temperature range of 560 to 590 °C for Al-15wt% Pb/15wt% fly-ash composite. For Al-15wt% Pb/20wt% fly-ash composite a decrease in density is observed in the temperature range of 560 to 590 °C. In the sintering temperature range of 500 to 560 °C, the liquid phase sintering occurs due to melting of Pb. But at 590 °C, in addition to liquid phase sintering of Pb, the diffusion of Al particles takes place resulting in nucleation and growth of new Al structure. This diffusion phenomenon of Al particles results in a decrease in the porosity and an increase in the density. For Al-15wt% Pb/20wt% fly-ash composite, the density decreases at 590°C owing to the spherical shape of fly-ash particles.

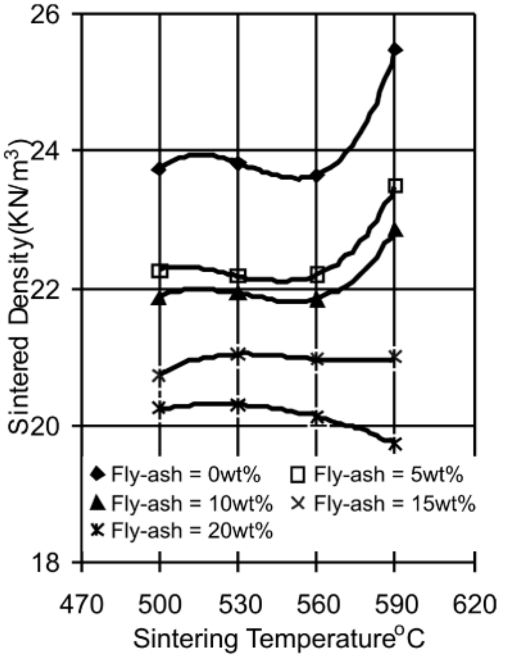

Figure 12: Effect of Sintering Temperature on Sintered Density of Al-15wt% Pb/fly-ash Composites Compacted at 200MPa

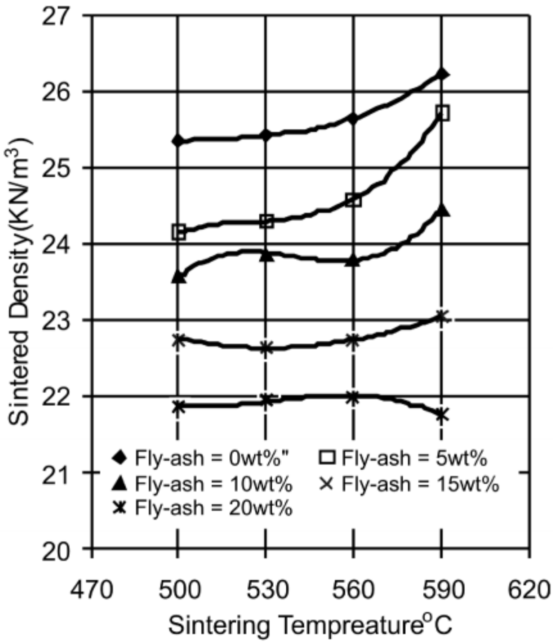

Figure 13: Effect of Sintering Temperature on Sintered Density of Al-15wt% Pb/fly-ash Composites Compacted at 300MPa

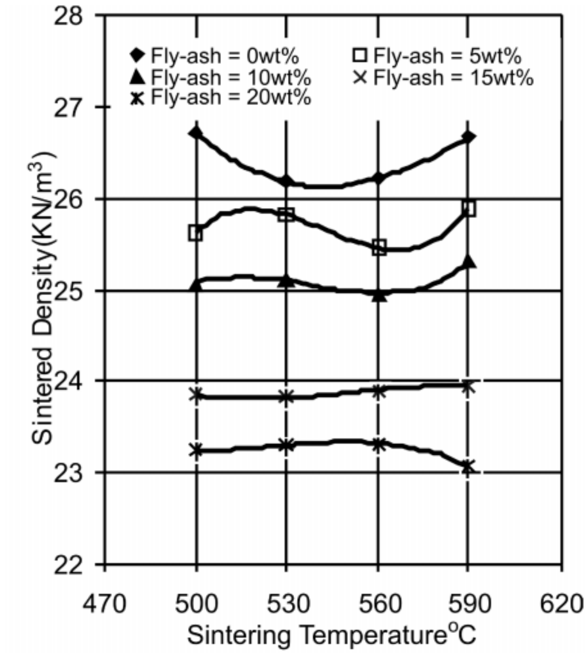

Figure 14: Effect of Sintering Temperature on Sintered Density of Al-15wt% Pb/fly-ash Composites Compacted at 400MPa

3.2. Sintered Porosity

The effect of compaction pressure on the sintered porosity at different sintering temperatures for Al-15wt% Pb/fly-ash composites is shown in Figs. 15 to 18. It is observed that the sintered porosity decreases with the increase in compaction pressure for all composites and at all sintering temperatures. Increase in compaction pressure causes better packing of particles and thus decreases the porosity of the composites. Figs 19 to 22 show the effect of fly-ash content on the sintered porosity for various composites and at different sintering temperatures. The addition of fly-ash to Al-15wt%Pb increases its porosity. The increase in porosity with the increase in wt% of fly-ash is due to the spherical shape of fly-ash particles. The spherical shape of fly-ash particles causes point contacts and hence increases the porosity of the composites. The effect of sintering temperature on the sintered porosity of the Al-15wt% Pb/fly-ash composites is shown in Figs. 23 to 25. There is a marginal change in porosity with the sintering temperature varying from 500 to 560°C and a decrease in the porosity with the increase of sintering temperature from 560 to 590 °C. This is due to the fact that the molten Pb is formed in the sintering temperature from 500 to 560 °C. This molten Pb fills the pores in the briquettes. With the further increase of sintering temperature to 590 °C, the liquid phase formed leads to rapid particle rearrangement and filling of voids resulting in decreased porosity. For Al-15wt% Pb/20wt% fly-ash composite, a small increase in the porosity is observed from 560 °C to 590 °C. This is because of large volume of void space caused by the spherical fly-ash particles.

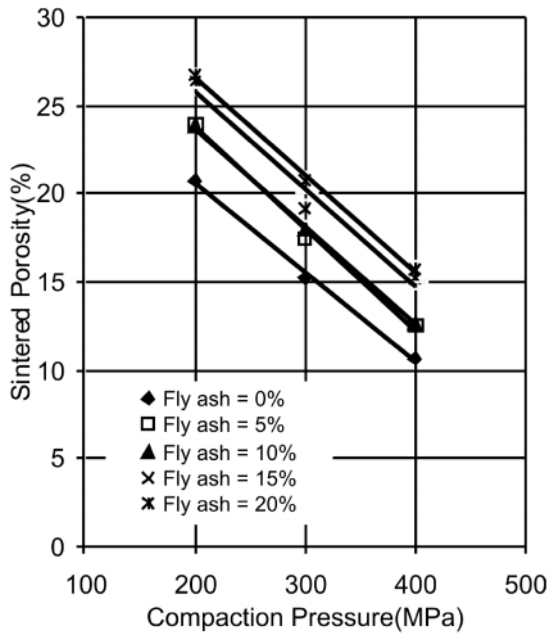

Figure 15: Effect of Compaction Pressure on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 500 °C

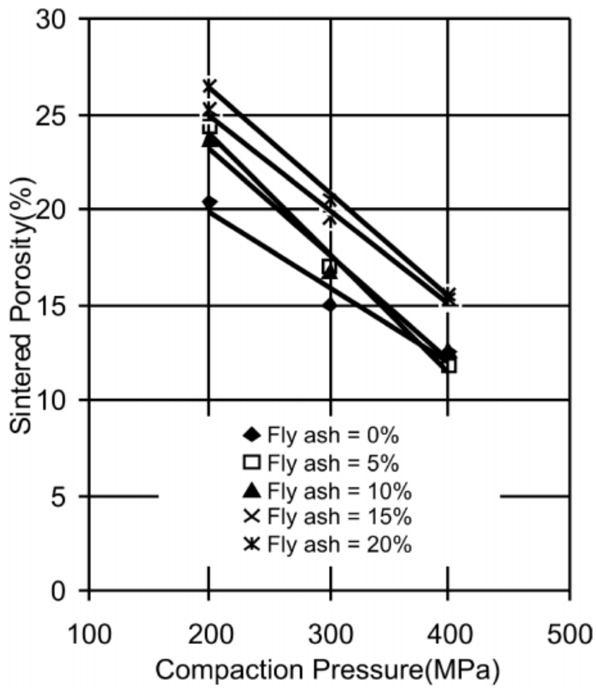

Figure 16: Effect of Compaction Pressure on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 530 °C

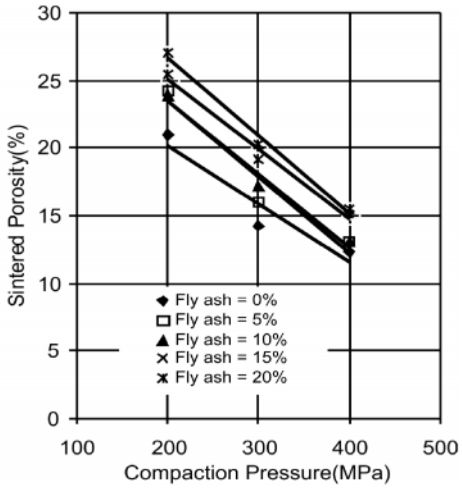

Figure 17: Effect of Compaction Pressure on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 560 °C

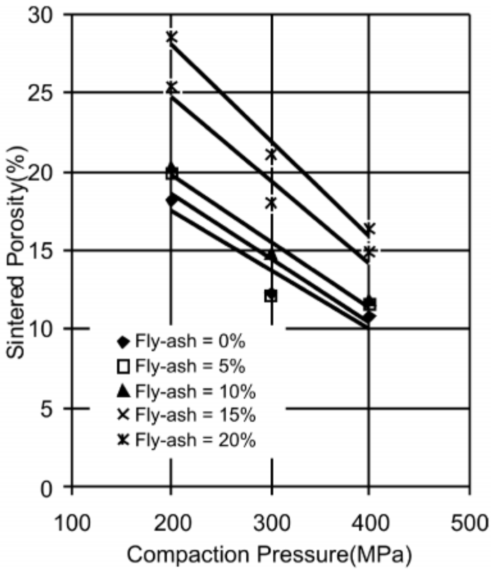

Figure 18: Effect of Compaction Pressure on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 590 °C

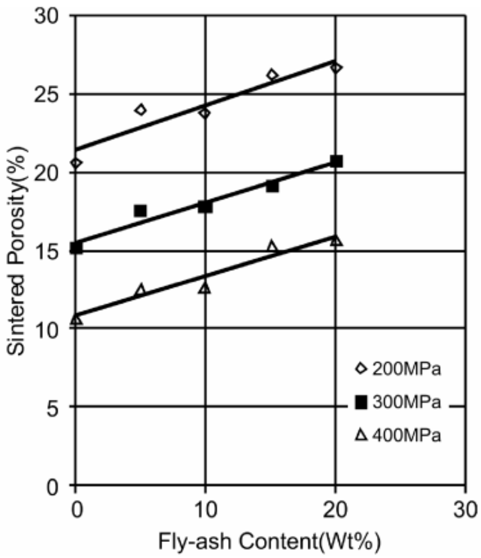

Figure 19: Effect of Fly-ash Content on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 500 °C

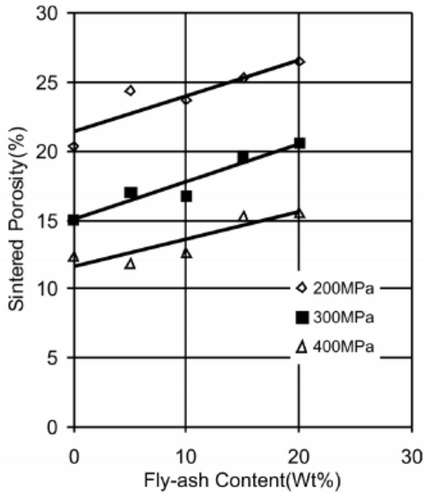

Figure 20: Effect of Fly-ash Content on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 530 °C

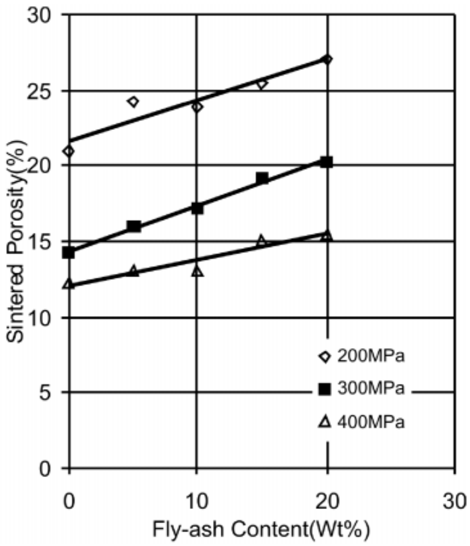

Figure 21: Effect of Fly-ash Content on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 560 °C

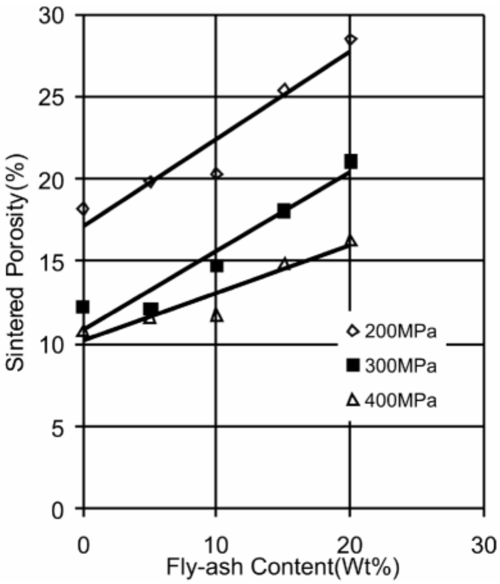

Figure 22: Effect of Fly-ash Content on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Sintered at 590 °C

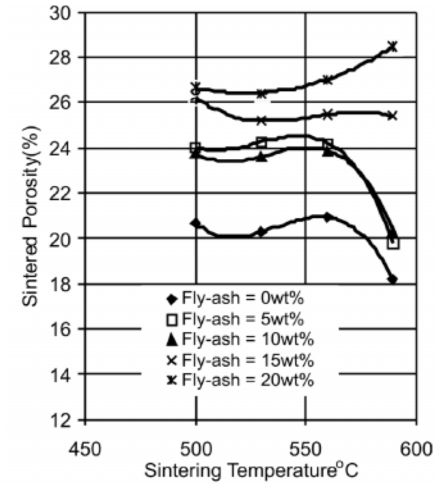

Figure 23: Effect of Sintering Temperature on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Compacted at 200MPa

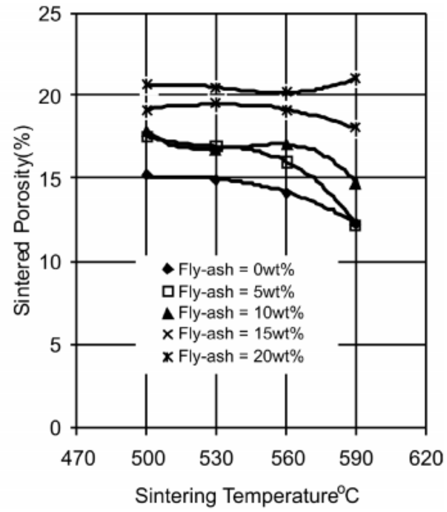

Figure 24: Effect of Sintering Temperature on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Compacted at 300MPa

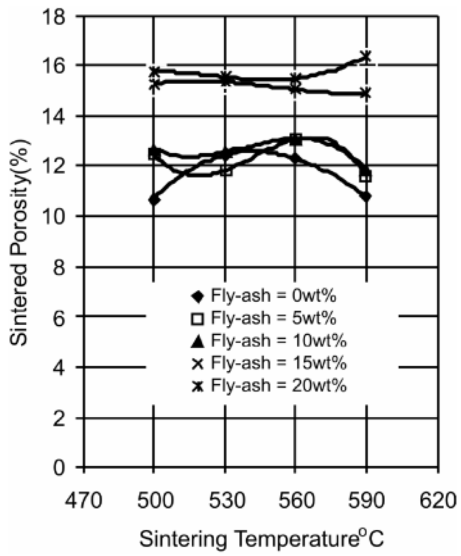

Figure 25: Effect of Sintering Temperature on Sintered Porosity of Al-15wt% Pb/fly-ash Composites Compacted at 400MPa

4. CONCLUSIONS

Al-15wt% Pb/fly-ash metal matrix composites were prepared by powder metallurgy technique involving single action die compaction process followed by sintering. The sintered density of the compacts increased with the increase in compaction pressure and its porosity decreased. With the increase in wt% fly-ash the sintered density decreased whereas the sintered porosity increased. The change in sintered density and sintered porosity in the temperature range of 500 to 560°C is marginal.

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