Effect Of Processing Parameters In SLS Of Metal-Polymer Powders

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Abstract

This paper describes the effect of processing parameters in SLS of metal-polymer powder mixtures. Test bars for measurement of strength and density were made from copper-PMMA powder mixtures using SLS. The effect of Energy Density during laser processing, effect of vector length, bed temperature, polymer melt index and initial binder content on part strength and density are discussed in this paper. The green part strengths and densities were found to increase with Energy Density upto a value of 6.0 cal/cm^2 and then they drop off due to polymer degradation. Parts made with lower vector lengths yielded higher strengths and densities than those with higher vector lengths. Parts processed with a low melt index polymer binder (around 6.0 gm/10min) showed higher strengths than parts processed with higher melt index binders . High strength values were obtained for green parts made from powders that had a greater initial binder content. Bed temperature did not have a very significant effect on part strength and densities.

Introduction

Selective Laser Sintering comes under the class of Solid Freeform Fabrication Processes for rapid manufacture of parts directly from a CAD model without part specific tooling or human intervention [1,2]. This technology has been developed at the University of Texas at Austin to produce polymer parts as well as indirect metal and ceramic parts that have polymer as an intermediate binder. There are a variety of material and processing issues involved in manufacture of green metal parts using an intermediate polymer binder, namely the polymer melt index, Energy density during laser processing of parts, vector length of part being fabricated, the bed temperature employed during processing and the content of polymer binder that is used for green part fabrication. This work is directed towards a better understanding of these various issues which would help in developing a good process control system for the SLS process and ensure quality and repeatability in the manufacturing process.

Experimental Procedure

Copper powder, -325 mesh (mean size of 5-10μm) which was used along with a polymer binder in green metal part fabrication by SLS, was obtained from Reade International, Rumson, New Jersey. PMMA and copolymers of MMA and BMA were used as intermediate binders for the metal powder in SLS processing. The synthesis of these polymer emulsions has been discussed in detail by Vail [3]. The polymer was obtained in powder form by spray drying the emulsion polymer in an Anhydro Model 1 Spray Drying Unit. All SLS processing experiments were carried out by mixing the polymer powder with the copper powder in the desired proportion. SLS processing was carried out in a nitrogen environment to keep the processing chamber inert. A layer thickness of 0.005 inches was used in all the SLS processing experiments. Three point bend specimens (3.0" x 1.0" x 0.25") were made by SLS for measurement of strength and density of green parts.

Results and Discussion

Effect Of Energy Density : One of the main issues in SLS is the amount of energy that goes into the surface for sintering the powder. For studying the effects of Energy Density on green part strength and density 3-point bend bars were made from copper-PMMA mixed powders and processed at Energy Densities varying from 2.0 to 7.0 cal/cm^2. The PMMA Melt Index was 31 gms/10min at 200C and 75psi load. The volume percent of polymer in the mixture was 40 %. The scan spacing was kept constant at 0.005 inches, the step period SP was set at 20μs, and the step size was varied from 16 to 56. The power for all the runs was fixed at 9.5 Watts. The strength data for the green bars as a function of the Energy Density, is shown in Figure 1. The strength of PMMA (MI = 31) is approximately 1150 psi [3]. The green strength for the SLS bars varies from 120 psi to 370 psi (between 10% to 32% of the polymer strength). We can see that the strength increases as the Energy Density increases from 2.0 to 6.0 cal/cm^2 and then falls off. The increase in strength with Energy Density is because of the increase in energy input to the surface which results in higher temperature and better flow and sintering. The drop in strength after an Energy Density of 6.0 cal/cm^2 is due to the decomposition of the polymer at high energy densities. The decomposition of the polymer can be inferred from the drop in density of the green part as the Energy Density is raised above 5.0 cal/cm^2. The plot of density with Energy Density is shown in Figure 2. The green density also shows a similar trend with Energy Density though there is more scatter in the data.

Effect Of Vector Length : The vector length plays an important part in determining the strength of the green object made by SLS. As the vector length increases the time delay between energy pulses increases thereby increasing cooling by radiation and convection and reducing the amount of sintering that is achieved for a given set of parameters. Vail et al. [3] have found that the green strength drops by more than a factor of two when going from 3 in. to 6 in. scan vectors for a PMMA coated silicon carbide powder processed by SLS. The effect of vector length on green part strength and density was studied by scanning a copper-PMMA mixed powder system at vector lengths of 3.0" and 1.0" respectively over a Energy Density range on 2.0-6.0 cal/cm^2. Figure 3 shows the plot of modulus of rupture with Energy Density for two vector lengths. There is dramatic drop in strength as the vector length increases from 1.0" to 3.0". Figure 4 shows the plot of percent green density with Energy Density for the same powder system with the different vector lengths. As expected the densities are much higher in the case of the green parts with lower vector lengths. At higher Energy Densities, however, the polymer starts to decompose and so the density and strength can begin to decrease for lower vector lengths. At lower Energy Densities the green strengths for the 1 in. scan vectors are about twice as much as those for the 3 in. scan vectors.

Effect Of Polymer Melt Index : The Melt Index of the polymer, as defined by ASTM D1238, is an important parameter in the SLS processing of metal powder using polymer as intermediate binder. The Melt Index determines the flow of the polymer and therefore the sintering of the powder under the laser beam. As the Melt Index depends inversely on the molecular weight of the polymer the strength of the parts decrease with increase in polymer Melt Index. To study the effect of Melt Index on strength and density three PMMA emulsions with melt indices of 6, 31 and 40 were separately spray dried. These were mixed with copper at a polymer composition of 40 vol% and processed by SLS. The laser power was fixed at 9.5 Watts, the step period (SP) was set to 20μsec, the Scan Spacing (SCSP) was set at 0.005 inches, and the Step Size (SS) was varied from 16 to 56 grid units. The effect of Melt Index on strength is shown in Figure 5. We can see that the strength of parts increases as the Melt Index decreases. A low polymer Melt Index results from a high viscosity and high polymer molecular weight. As the strength is proportional to molecular weight, the green part strength increases with decrease in Melt Index. This trend is in good agreement with the data of Vail [3] for copolymer coated A-5000 soda-lime glass powder (copolymers 80/20-4-S, 80/20-6-S, 80/20-8-S). Vail also found that when binder melt flows were substantially smaller (in the range of 0.07 to 0.96 gms/10min) the modulus of rupture for the green SLS bars were often lower than the green SLS bars made with binders that had higher Melt Indices. The effect of Melt Index on green density is shown in Fig 6. The parts made from all the three polymer binders have comparable densities ranging from 41% to 46%. The higher the Melt Index the better the flow and therefore greater the sintering and the resulting green density. However in SLS the effect of Melt Index on density is not very pronounced as for the most part the density seems to be determined by the interlayer porosity that occurs on layering powder.

Effect Of Bed Temperature : In SLS processing the material directly under the laser beam is at a much higher temperature than the material that has already been exposed to the laser energy or the material unexposed to the laser beam. Also, the surface temperature of the powder under the laser is much higher than that of the material below the surface. The temperature gradients in the laser heated material can cause differential volume changes because the sintering rate is a function of temperature, and hence residual stresses can build up in the material. The actual residual stress distribution in the sintered part depends on the temperature variations in the powder bed, the associated cooling rates, and the ability of the material to stress relax. Polymers show rapid stress relaxation at temperatures larger than their glass transition temperature.

During SLS processing of powders the part side powder surface is usually heated to prevent curling of the part due to thermal stresses on laser irradiation. The metal-polymer powder systems the bed temperature is usually set close to the glass transition temperature of the polymer binder (about 2-3° below T_g). This helps in effective sintering and also removes curling. The effect of bed temperature on strength and density of green parts was studied for a copper-copolymer mixed powder system. The copolymer composition was 40% by volume. Three different bed temperatures, 85,75 and 65°C, were used. The laser power was fixed at 9.5 Watts, the step period (SP) was set to 20μsec, the Scan Spacing (SCSP) was set at 0.005 inches, and the Step Size (SS) was varied from 16 to 57 grid units. Three point bend bars were made for strength tests. Figure 7 shows the effect of bed temperature on part strength. It is seen that the green part strength increases with the bed temperature, but this increase is limited to the glass transition temperature of the polymer. If the bed temperature is kept above the glass transition temperature of the polymer the entire powder bed cakes up and the SLS run would get aborted. Parts scanned at bed temperatures near the polymer T_g showed minimal or no curl compared to those scanned at lower temperatures. Figure 8 shows the % density of the green parts with bed temperature at different Energy Densities. We find that bed temperature has no significant effect on the green part density.

Effect of Amount of Polymer Binder In SLS : Another factor that is to be considered in SLS processing of metals with a polymer binder is the amount of polymer to be used as binder. Lower amounts of polymer will be desirable if the aim is to go to fully dense metal parts with low shrinkages. If, however, the aim is to obtain a lightly sintered metal or oxidized metal preform with subsequent infiltration by another lower melting metal or a liquid epoxy resin then it is not necessary to ensure a low binder content in the green part. The effect of binder volume fraction on part strength is shown in Figure 9. This curve suggests that high binder content might be desirable for producing green parts with good strengths. As the amount of polymer increases there is greater sintering and bonding with the metal powder and hence there is an increase in strength for the green compact.

Summary

In this paper the effects of material properties and processing issues have been explored. It is found that energy densities around 6.0 cal/cm^2 yield parts with good green strengths. Green parts fabricated with low Melt Index PMMA showed greater strengths than those processed with higher Melt Index PMMA. Parts made with lower vector lengths yielded greater strengths than those made with higher vector lengths. However, it is important to note that too small a vector length could lead to polymer degradation and hence lower strength values. Bed Temperature does not have a significant impact on strength values in the temperature ranges considered in processing. However it is necessary to keep the bed temperature close to the glass transition temperature (about 2-3° below T_g) to prevent warping of parts during SLS processing. Higher binder content in raw powder leads to greater strengths on processing. The results obtained in this work can be used as a guideline for SLS processing of metal parts with an intermediate polymer binder.

Acknowledgment

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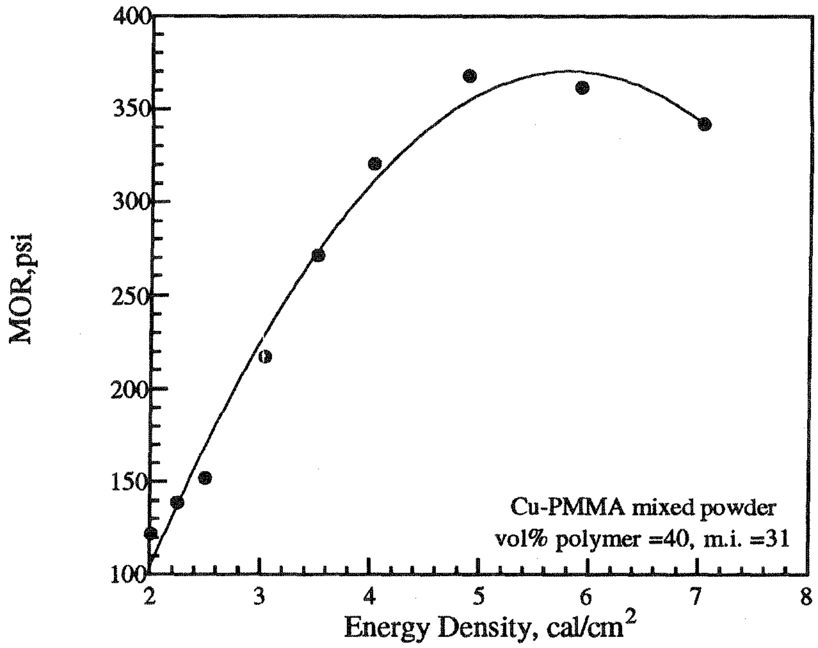

Figure 1 : Effect of Energy Density On Green Part Strength

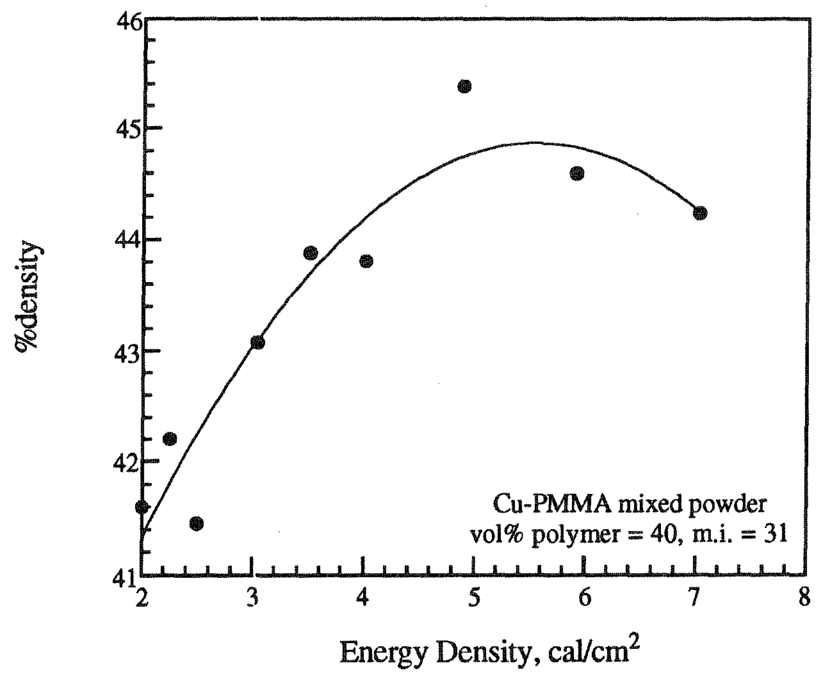

Figure 2 : Effect Of Energy Density on Green Part Density

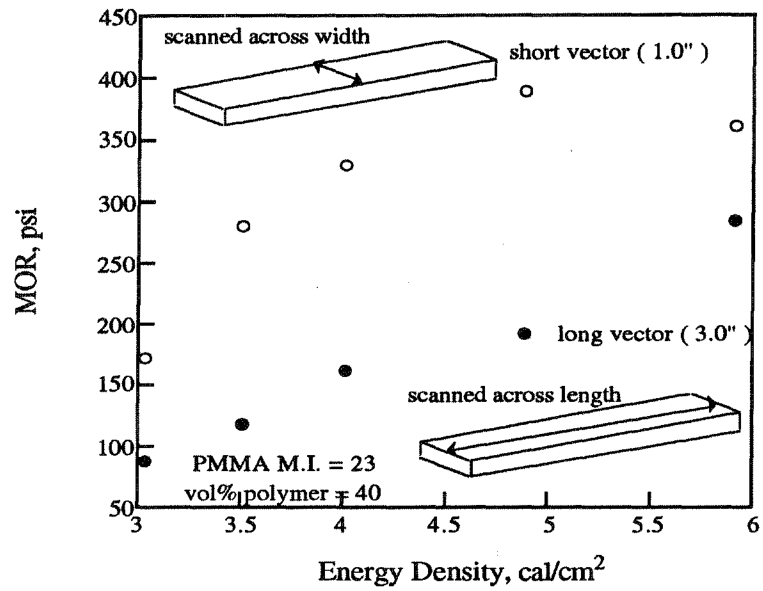

Figure 3 : Effect of Vector Length on Green Strength

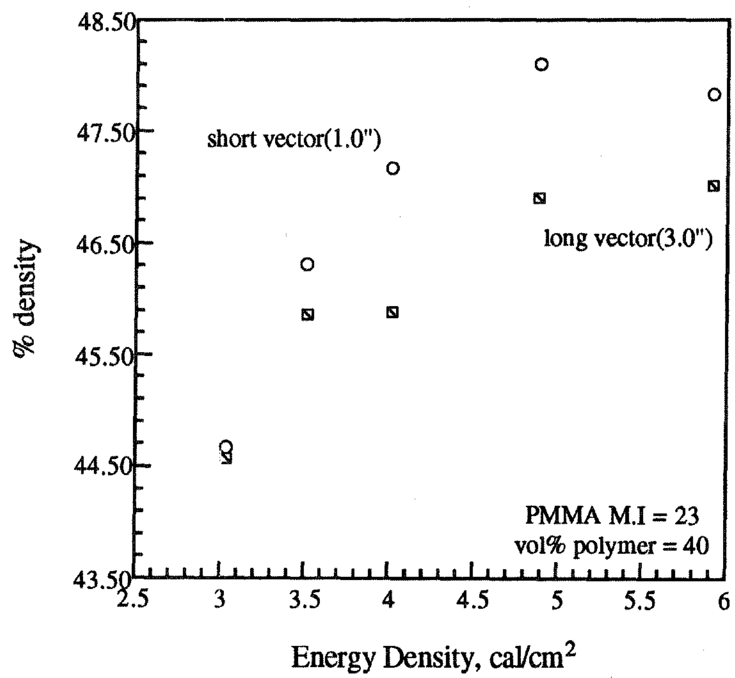

Figure 4 : Effect of Vector Length on Green Density

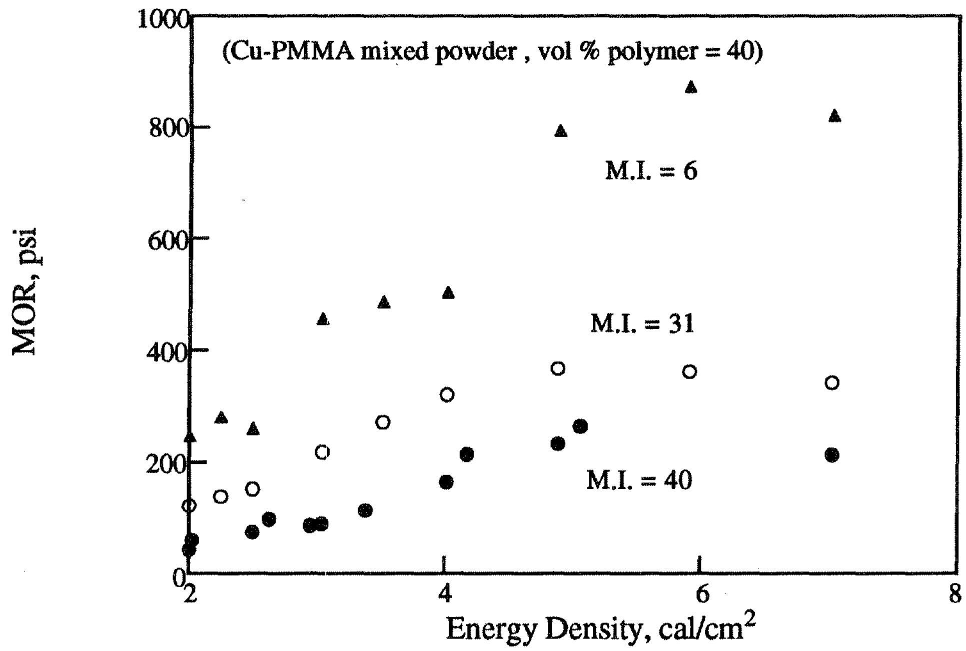

Figure 5 : Effect Of Polymer Melt Index On Green Strength

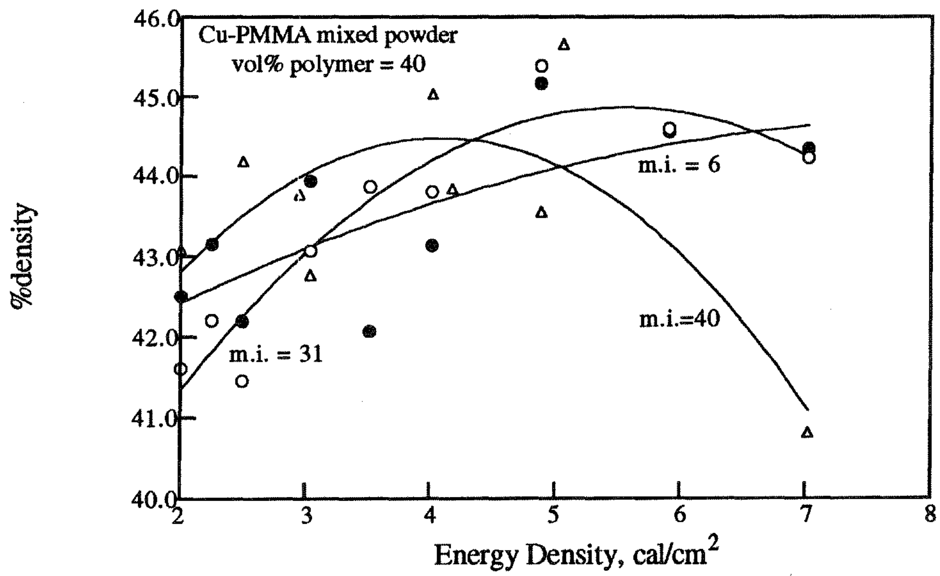

Figure 6 : Effect Of Polymer Melt Index on Green Density

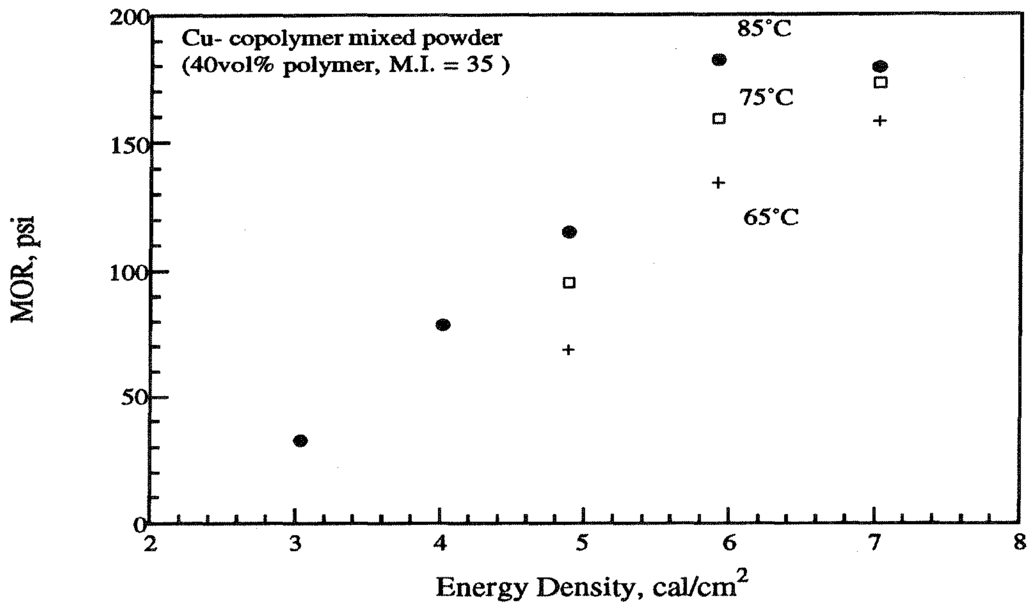

Figure 7 : Effect of Bed Temperature on Green Strength

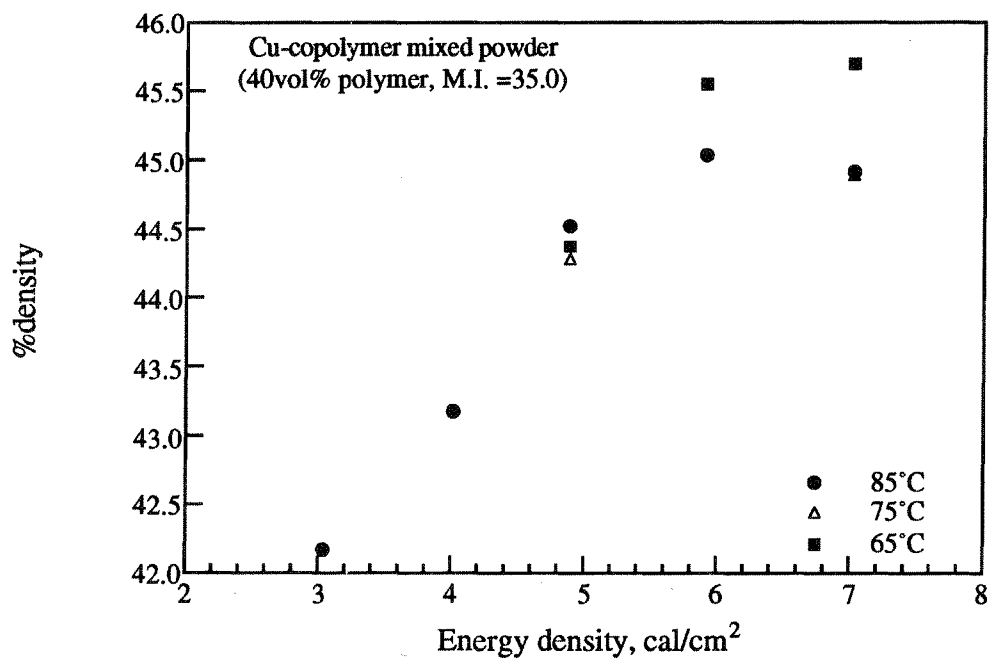

Figure 8 : Effect of Bed Temperature on Green Density

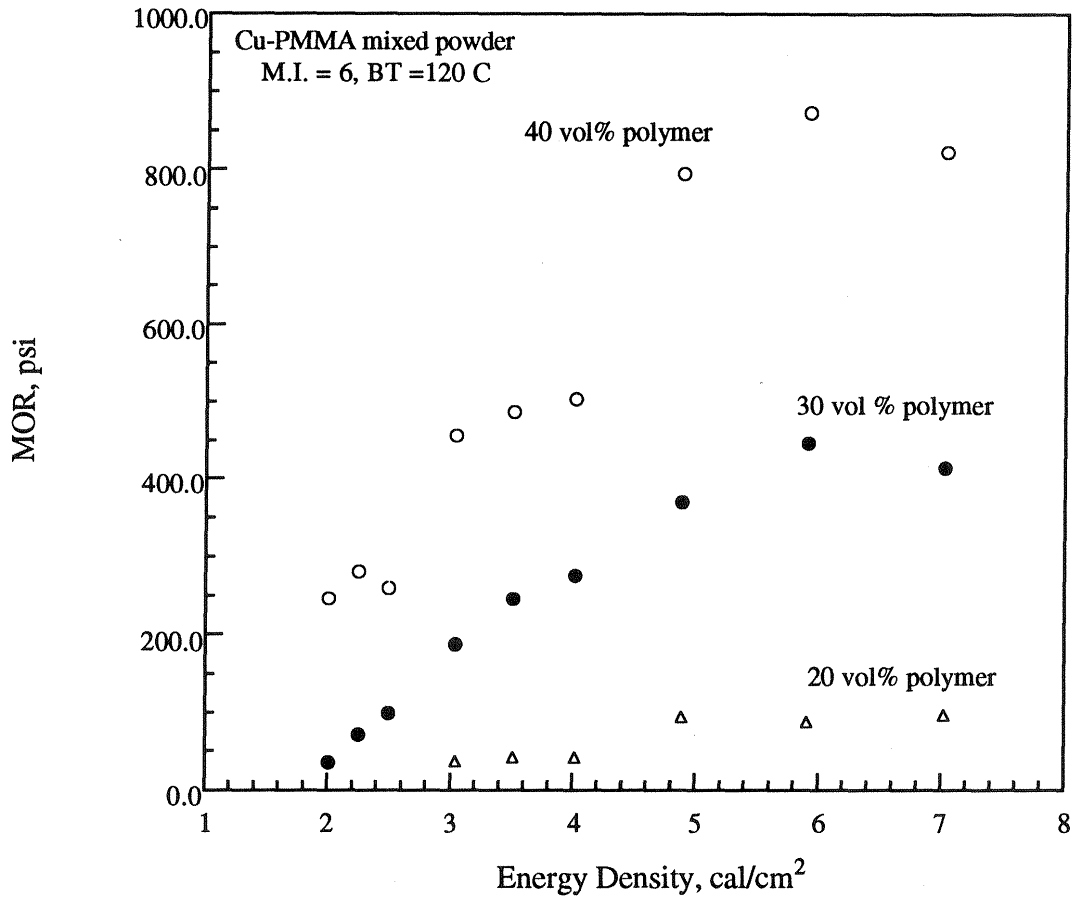

Figure 9 : Effect of Polymer Content in Raw Powder on Green Strength