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A simple method for the estimation of optimum binder content in baked carbon mixes

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A detailed study is presented of the optimum amount of binder in various carbon mixes consisting of calcined petroleum coke of different particle size distributions as filler and coal tar pitch as binder. These fillers were subjected to bulk density measurements prior to wet mixing with various amounts of binder and were then shaped into cylinderical blocks by compression moulding. The blocks obtained were measured for green apparent density before being baked to a temperature of 950° C. The baked blocks were then subjected to apparent density, electrical resistivity and crushing strength measurements. The optimum binder contents for these baked carbon mixes obtained on the basis of maximum apparent density, maximum crushing strength and minimum resistivity, were plotted against the bulk density of the corresponding fillers. The optimum binder content on the basis of apparent baked density and crushing strength is found to be an inverse function of the bulk density of the filler. Thus, knowing the bulk density of the particular filler, it is possible to predict the optimum binder content in the corresponding carbon mix with the product diameters up to 19 mm.

1. Introduction

Carbon products are fabricated from a mixture of carbon filler and binder, for example coke and pitch respectively. The mixture is shaped by moulding or extrusion and is then baked. The quality of the baked product is dependent upon the quality of the green carbon. Crack-free green carbon is good if it contains an optimum amount of binder, which in turn depends upon the particle size distribution of the filler that makes up the product. The baked carbon mixes containing an optimum amount of binder have high density, high strength and low resistivity. The level of binder above or below this optimum leads to comparatively inferior properties [1–3]. The prediction of optimum amount of binder from the result of the baking studies is a time consuming process, which is further limited by the industrial equipment producing particles. That is to say, if the particle size distribution of the filler changes, the optimum amount of binder needed for the mixes varies accordingly. A survey of the literature reveals that there is no direct method of predicting the optimum amount of binder in the carbon mixes. With these ideas in view, a study was undertaken to discover a simpler method for estimating the optimum amount of binder in the carbon mixes without actually processing it. In the present investigation one filler was chosen with seven different particle size distributions, and the optimum amount of binder was predicted in each case with respect to physical characteristics such as apparent density, crushing strength and electrical resistivity. The optimum binder contents obtained this way for various carbon mixes are correlated with the bulk density of the corresponding fillers. The results are described and discussed below.

2. Experimental procedure

The filler used in the present investigation consisted of calcined petroleum coke collected in seven batches, having different particle size distributions

TABLE I Optimum binder data for various carbon mixes

Batch	Petroleum coke specification B.S. mesh	Bulk density of the filler ($g\ cm^{-3}$)	Optimum binder content (%) on the basis of			
			Green apparent density	Baked apparent density	Crushing strength	Electrical resistivity
A	−60 + 100	0.860	40.0	34.0	30.0	40.0–45.0
B	−100 + 200	0.845	34.5	34.5	31.0	42.5–47.5
C	−200 + 300	0.75	49.0	38.0	36.0	52.5–57.5
D	−300	0.558	49.0	45.0	45.0	52.5–57.5
E	(−30 + 60) 60 Parts and −300 40 Parts	0.891	38.0	34.0	29.0	45.0–48.0
F	(−100 + 200) 40 Parts and −300 60 Parts	0.790	40.0	34.0	32.5	42.5–46.0
G	(−200 + 300) 15 Parts and −300 85 Parts	0.650	45.0	42.0	40.0	42.0–43.0

as shown in Table I. These dry fillers were subjected to bulk density measurements [4] prior to wet mixing as follows. The apparatus consisted of a measuring cup of 100 cm^3 capacity, whose diameter was equal to half its height. The funnel used for holding the powder had a cone angle of 40°. An oven dried sample weighing 100 g was taken from the sized fractions and mixed in a small sized double cone mixer for 150 revolutions. The conically mixed material was transferred to the funnel, the bottom end of which was kept closed with a flat strip. When the sample was poured into the funnel, the flat strip was removed quickly and the material allowed to fall freely into the cup. After all the material had fallen into the cup, the excess material on the top of the cup was scrapped off with a straight edge. Care was taken to see that no jerks were given to the apparatus thereby causing some packing other than the loose one to take place. The material in the cup was then accurately weighed to the nearest 0.01 g: the weight in grams of 1 cm^3 of the powder gave its bulk density. Generally, a minimum of three such operations were carried out and the results averaged out.

Each filler was roll-mixed at 120° C with various amounts of coal tar pitch binder (Ring and Ball softening point 78° C) from 20 to 65 parts by weight of dry filler. The resulting mixtures were ground cold and about 13 g portions taken from each batch were moulded in an oil-heated die in the form of cylindrical blocks of 19 mm diameter under a load of 550 kg. Seven such blocks were made each time for various binder proportions for all the batches. The green blocks so obtained were subjected to apparent density determination by measuring their mass, length and diameter. These blocks were then baked in an electrical muffle furnace to 950° C in a five-day baking cycle. The baked blocks were measured for apparent density, electrical resitivity and crushing strength. The electrical resitivity was determined by passing a suitable current through the cross-section of the block kept between two thick copper plates and measuring the potential drop across two probes placed along the length of the blocks with the help of an accurate microvoltmeter. The crushing strength was determined by placing the block between two thick steel discs and applying an increasing load at its top end at a constant rate of 0.05 $cm\ min^{-1}$ till the block broke.

3. Results and discussion

Figs. 1 and 2 represent the variation of the green apparent density of carbon mixes as a function of binder content in the green mix. It is seen from the curves that the green density in each case rises to a certain maximum, and then falls with further increase of binder content in the mix. This indicates that there is an optimum amount of binder for each mix which gives rise to a maximum apparent density in the green carbon mixes. However, if these optimum contents of binder are plotted against the bulk density of the filler in the respective carbon mixes, we get two types of curves as shown in Fig. 3. The thick dark line relates to the single petroleum coke fractions while the dotted line corresponds to binary mixtures of petroleum coke fractions in their fillers (Table I). It is easily seen that as the mean size of the particles reduces from 200 μm (−60 + 100 B.S. mesh) to 112 μm (−100 + 200 B.S. mesh) there is a decrease in the quantity of optimum binder content. But with further decrease in particle sizes below 112 μm up to 64 μm (−200 + 300 B.S. mesh) the optimum amount of binder increases and later on it becomes almost independent of the particle size or bulk

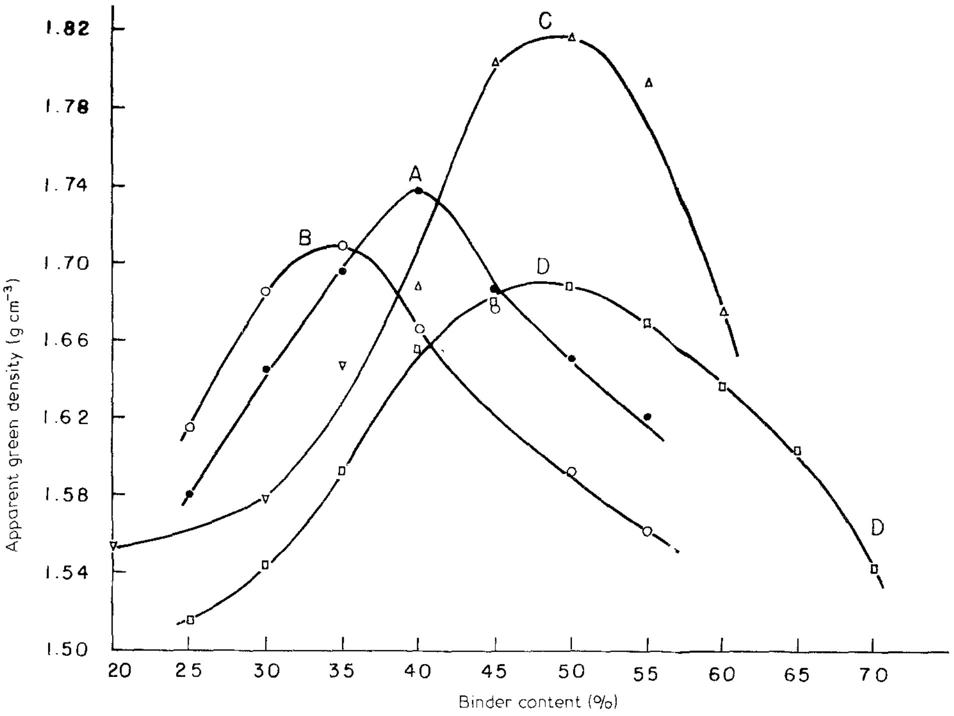

Figure 1 Green densities of various carbon mixes as a function of binder content.

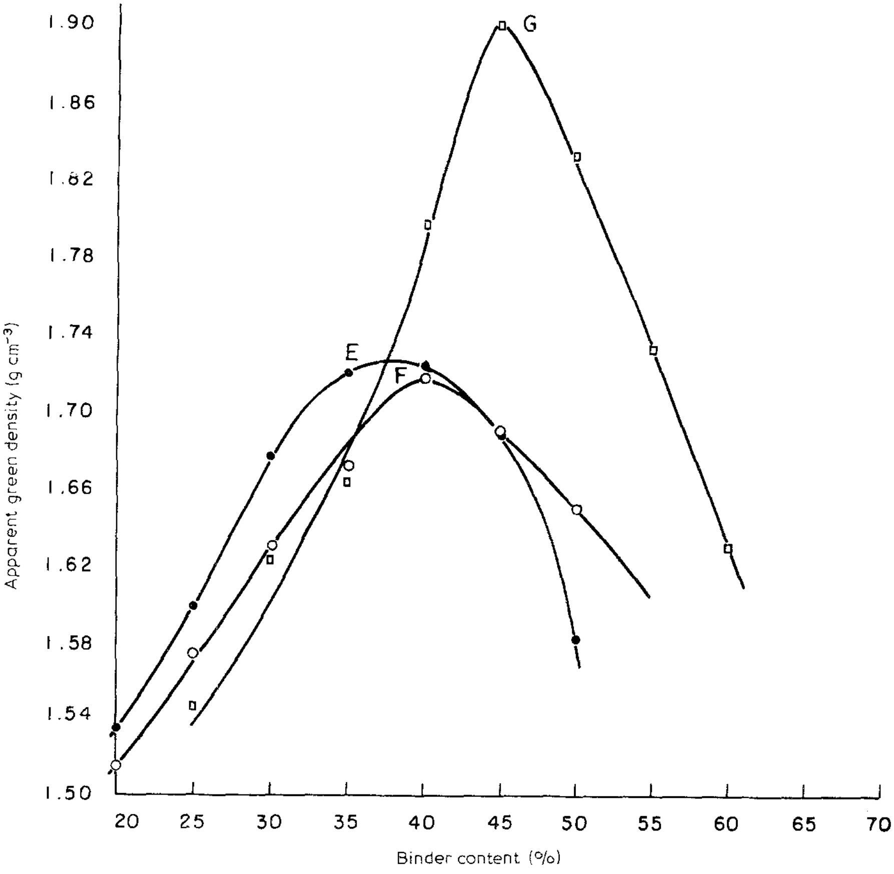

Figure 2 Green densities of various carbon mixes as a fucntion of binder content.

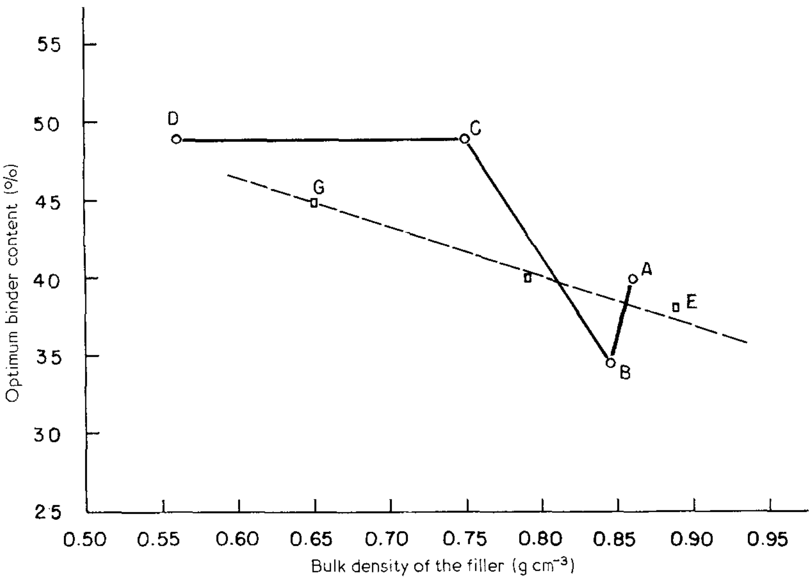

Figure 3 Optimum binder content in various green carbon mixes on the basis of maximum apparent green density as a function of bulk density of the filler.

density of the filler. The fall from A to B may be attributed to the following reasons. The open porosity of the filler consists of pores within the particles as well as voids among the particles. The bed formed from coarser filler particles obviously has bigger voids in addition to the higher open porosity associated with them. Then the decrease in the particle size from A to B without significant reduction in bulk density, would require a lesser amount of binder for filling the pores in the filler B compared to that in A. With further reduction in the particle size below 112 μm (−100 + 200 B.S. mesh) the pores within the particles remain the same, but the number of voids as well as the pore volume in the filler increases, hence more binder is required to fill it up. When the size of the particles decreases below 64 μm, the particles become flatter and a shape factor comes into play. Hence even though the bulk density decreases, the open void either does not change much or the binder is not able to penetrate in fine voids. This results in flattening of the curve in Fig. 3. However, for the binary mixtures optimum binder increases linearly with the decrease in the bulk density of the filler. This is obviously due to increase in the volume of voids. The difference in the pattern of curves for single sized fractions from that of binary mixtures is the result of packing of finer fractions into the coarser ones in the latter case.

Figs. 4 and 5 represent the variation of the apparent baked density as a function of binder content in the various carbon mixes. Here again baked density increases to a certain maximum and falls with a further increase of binder content. If the optimum binder content predicted from maximum baked density in the carbon mixes is plotted against the bulk density of the respective filler, straight line pattern is observed as shown in Fig. 6. This indicates that optimum binder needed for any filler is an inverse function of its bulk density. This is obvious because more binder is required as fineness of filler increase. This curve will help in finding the optimum binder content for the given filler of any particle size distribution from the bulk density of the latter.

Figs. 7 and 8 represent the variation of the crushing strength of the various carbon mixes as a function of binder content in them. It is indicated from the curves that crushing strength follows the similar pattern to that in the case of baked density. It is also noteworthy that as the bulk density of the single filler fractions goes on decreasing, the crushing strength increases, and this may be attributed to the increased bonding of the particles in the mix. If the optimum binder content, as predicted from the crushing strength data, is plotted as a function of bulk density of the respective filler, a straight line is obtained as shown in Fig. 9. This indicates that optimum binder determined from maximum crushing strength of the baked carbon mixes is an inverse function of the bulk density of the respective filler. This curve can help in determining the optimum amount of binder needed for the given filler as well as for getting any

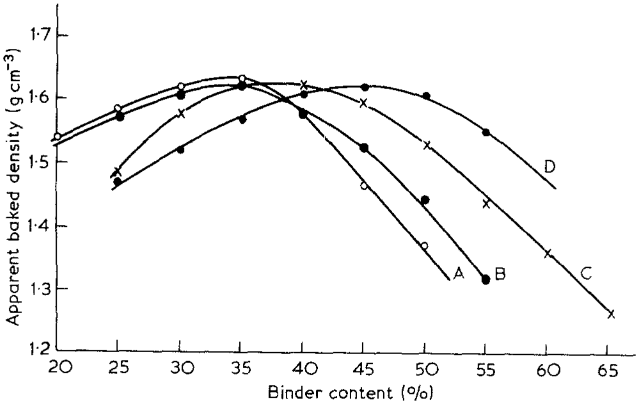

Figure 4 Apparent baked densities of various carbon mixes as a function of binder content.

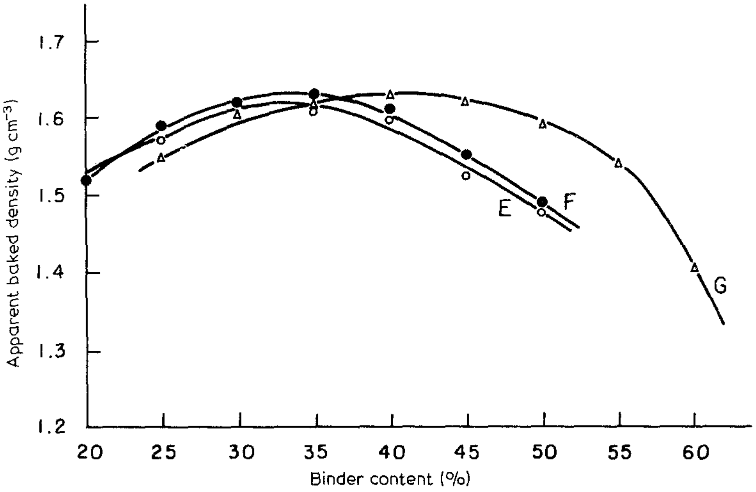

Figure 5 Apparent baked densities of various carbon mixes as a function of binder content.

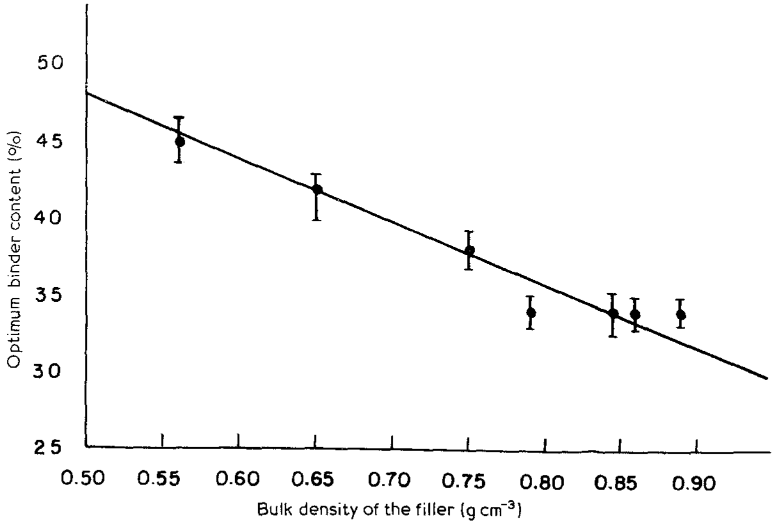

Figure 6 Optimum binder content in various baked carbon mixes on the basis of maximum apparent density as a function of the bulk density of the filler.

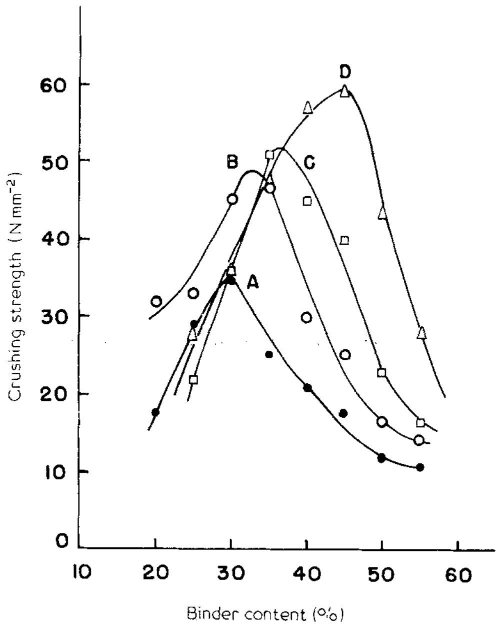

Figure 7 Crushing strength of various baked carbon mixes as a function of binder content.

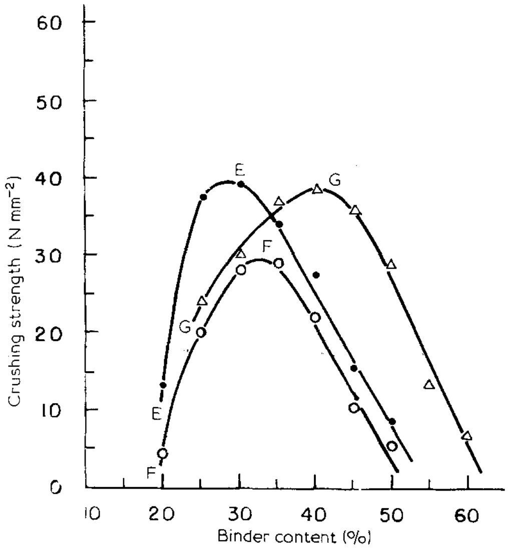

Figure 8 Crushing strength of various baked carbon mixes as a function of binder content.

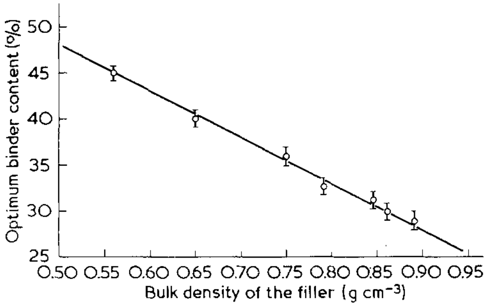

Figure 9 Optimum binder content in various baked carbon mixes on the basis of maximum crushing strength as a function of bulk density of the filler.

desired strength of the carbon mixes by choosing its bulk density. The curves of crushing strength data seem to be sharper than those of the baked density data, though optimum binder content for both characteristics show a similar linear relation with the bulk density of the fillers.

Figs. 10 and 11 represent the variation of the electrical resistivity of the various carbon mixes as a function of the binder contents in them. All these curves show a drop in their resistivity up to a certain binder content and afterwards they show an increase with further increase in the content of binder in the mix. The optimum binder obtained from the least value of the electrical resistivity is little higher than that obtained from the baked density or crushing strength considerations. If the optimum binder content obtained from electrical resistivity data is plotted against the bulk density of the respective fillers, we get two types of curves as shown in Fig. 12, one belonging to the pure single filler fractions, and other corresponding to binary mixtures of petroleum coke fractions. If the bulk density of the single fractions is slowly reduced, there is an increase in the optimum binder content up to a certain level of bulk density beyond which the optimum binder becomes almost constant. For binary mixtures of petroleum coke fractions, we see that optimum binder content needed increases in a linear fashion as the bulk density of the mixtures increases, but the values of the resistivity of the various mixes remains almost the same at their optimum binder contents.

It is seen from Table I that optimum binder content needed for various carbon mixes from the baked density considerations agrees reasonably with that obtained from crushing strength considerations. These values, however, do not tally with the optimum binder needed from view point of electrical resistivity. The optimum binder for electrical resistivity data happens to be higher than that from the baked density or crushing strength considerations, but since the change of electrical resistivity is not sharp about the optimum, one can easily tolerate a slightly higher resistivity value in conjunction with maximum baked density and crushing strength. It can therefore be said that bulk density of the filler is an important parameter

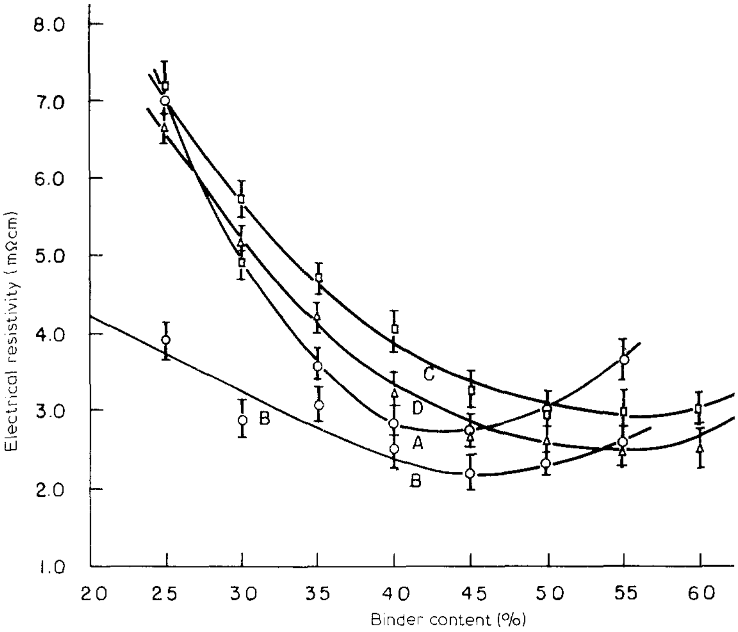

Figure 10 Resistivity of various baked carbon mixes as a function of binder content.

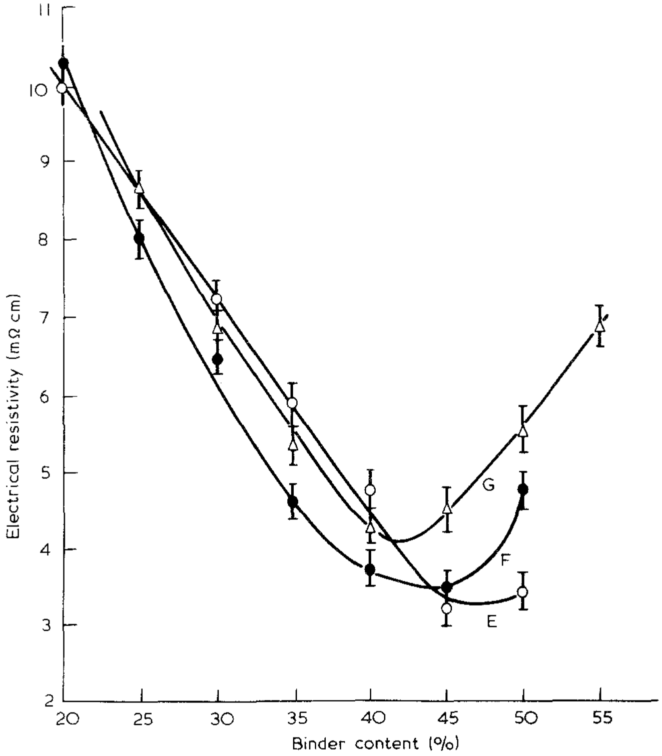

Figure 11 Eelectrical resistivities of various baked carbon mixes as a function of binder content.

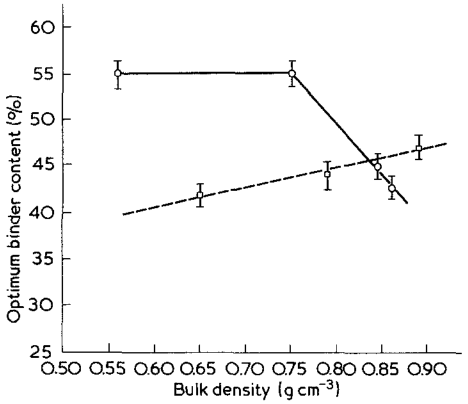

Figure 12 Optimum binder content in various baked carbom mixes on the basis of least electrical resistivity as a function of the bulk density of the filler.

for estimating the optimum amount of binder in baked carbon mixes.

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