HIGH PERFORMANCE FERROUS P/M MATERIALS FOR AUTOMOTIVE APPLICATIONS

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INTRODUCTION

The majority of automotive components (transmission, chassis, suspension, and engine) for which parts with densities up to about 7.0 g/cm3 are suitable have already been converted to P/M and there are few opportunities for growth in this density range. In order to meet the requirements of more demanding applications there has been a trend toward higher densities through the use of infiltration, double pressing/double sintering, or powder forging (l - 4) to produce parts such as synchronizer hubs, crankshaft sprockets, chain sprockets, gerotors, steering column tilt levers, planetary gear carriers, parking gears shift levers, and connecting rods. While powder forging has been shown capable of producing parts, which are superior to wrought, or cast products process economics have limited market penetration by this technology (5). The double press and sinter route also adds process costs and is probably too expensive for other than premium applications. There is a real need for a systems approach that will permit double pressed and sintered or infiltrated performance characteristics to be achieved by means of single compaction processing.

The mechanical properties of P/M materials are directly related to their microstructure and the size, distribution, and morphology of the porosity they contain. Alloying additions are made to develop specific material performance characteristics. However, the manner in which the alloys are constituted has a significant effect on the porosity and microstructure of the final product (6).

ALLOYING METHODS

The alloying methods used for the production of ferrous P/M materials can be divided into the following categories:

- Admixing
- Partially alloying (Distaloys ®)
- Prealloying

The alloy powders produced by each are illustrated schematically in Figure. 1

Admixed Powders

Mixing of iron powders with alloying additions, lubricants, and graphite in double cone or V-blenders is the method used to produce the majority of ferrous P/M alloys. Typical alloying additions include copper, nickel, carbon in the form of graphite, and phosphorus in the form of ferrophosphorus, Fe_3P. While this is undoubtedly the easiest way of preparing an alloyed powder, producing a uniform 'mixture requires the mixing equipment, mixing procedure, raw materials, and control methods to be selected with utmost care. Many powder users prefer to have their raw material suppliers prepare press-ready mixes containing all the required ingredients because the powder supplier usually has more efficient equipment and greater experience in the handling of powders.'

The function of the alloying ingredients determines the particle size and shape to be used. Unfortunately, these seldom coincide with the optimum powder characteristics for mixing. Although this can make it difficult to achieve a uniform mix and prevent it from segregating and dusting, such mixes are routinely produced and shipped over large distances by adopting proper mixing procedures and appropriate packaging methods. In April 1989 Hoeganaes Corporation started shipping press-ready premixes from a fully automated state of-the-art facility in Milton, Pennsylvania - see Figure 2. This facility increases premixing capacity at Hoeganaes by 35%.

Even materials produced from uniform mixtures of iron powder and alloying additions will have heterogeneous microstructures and non-uniform hardness, particularly those that contain nickel - see Figure 3. Diffusion of alloying elements will take longer than with partially alloyed powders and admixed powders will rarely reach a comparable degree of uniformity because finer alloying additions can be used in the production of the partially alloyed powders.

Partially Alloyed Powders

Partially alloyed or diffusion bonded powders sold under the name Distaloy® have been used for quite some time for the production of high strength sintered components (7). The typical characteristics of Distaloy 4600A and 4800A

(Weight %)

	Ni	**Mo**	**Cu**	**C**	**Oxygen**
Distoloy 4600 A	1.8	0.5	1.5	0.01	0.13
Distoloy 4800 A	4.0	0.5	1.5	0.01	0.13

Apparent Density 2.90 g/cm^3 Flow 27 sec./50g

Table 1: Typical properties of Distaloy 4600A and 4800A

The production of these powders involves the heat treatment of a mixture of iron powder and alloying elements in a reducing atmosphere. During this treatment, the alloying elements partially diffuse into the iron powder and a metallurgical bond is achieved.

There are a number of advantages associated with this approach to alloying. Because the alloying elements are only partially alloyed, the high compressibility of the base iron is maintained and the green strength is increased. Fine powders of the alloying elements can be added to the iron powder without the risk of segregation and dusting during transport and handling of the powder mix. Segregation may lead to compositional variations within parts and from part to part and may contribute to variation in dimensional change during sintering. Dusting leads to loss of alloying additions with a resultant reduction in performance and may also contribute to variation in dimensional change during sintering. Reduced segregation and dusting makes it easier for the parts producer to consistently meet close dimensional tolerance requirements.

Diffusion bonding the fine particle size alloying elements to the base iron reduces their tendency to form lumps or agglomerates during subsequent mixing with graphite and lubricant. The alloying additives will thus be more evenly distributed. The microstructures of materials produced from partially alloyed powders are heterogeneous (Figure 4), and do not exhibit uniform hardness unless they are sintered at very high temperatures for long times to promote diffusion. However, materials produced from Distaloy powders exhibit a superior combination of strength and toughness, which has yet to be matched by, prealloyed materials (6, 8 -11). Some authors have erroneously inferred that microstructural uniformity assures superior mechanical properties for P/M component (12).

Prealloyed Powders

Prealloyed powders consist of particles within which all the alloying elements are homogeneously distributed. They are generally produced by water atomization of liquid alloy steel. Water atomized powders are characterized by **dense** particles with regular shape. With prealloyed powders, no further homogenization during sintering is necessary and materials produced from **prealloyed powders have a homogeneous** microstructure and uniform **hardness see Figure 5.** Sintering time and temperature will, **however, influence pore size** and shape (6). Prealloyed powders result in materials with greater hardenability compared with materials produced from partially alloyed or admixed powders.

Prealloyed powders are generally less compressible than pure iron powder because of the solid solution strengthening effect of the alloying elements. The increase in particle hardness is roughly proportional to the concentration of alloying element and the magnitude of the effect varies considerably from one element to another. The transition elements have little influence, whereas elements with atomic radii deviating greatly from that of iron have a pronounced effect. Elements which go into interstitial solid solution in the iron reduce the compressibility of the powder to the greatest extent - see Figure 6 (13,14). For this reason, carbon is usually added separately as graphite.

Highly Compressible Low-Alloy Powders

Chromium has little effect on compressibility but its use as an alloying addition in water atomized powders is restricted because of the stable oxides it forms. Molybdenum has only a minor effect on compressibility, makes a significant contribution to hardenability and its oxides are reducible under standard powder processing conditions.

Two new low-alloy powders have therefore been developed based on molybdenum as the principal alloying 150 addition. The typical chemistries and physical characteristics of these powders, Ancorsteel 85 HP and Ancorsteel HP, are shown in Table 2.

	(Weight %)			
	C	Mn	Mo	Oxygen
Ancorsteel 85 HP	< 0.01	0.14	0.85	0.07
Aneorsteel 150 HP	< 0.01	0.14	1.50	0.07

Apparent Density 2.90 g/cm^3 Flow 24 sec.150g

Table 2: Typical properties of Ancorsteel 85 HP and Ancorsteel 150 HP.

Both powders are highly compressible; Ancorsteel 85 HP can achieve a green density of 6.8 g/cm3 at 30tsi with 1% admixed zinc stearate while Ancorsteel 50 HP reaches 6.7 g/cra3 under similar compaction conditions - Figure 7. Ancorsteel 150 HP has the highest hardenability of any commercially available low-alloy powder.

These new Low-alloy powders along with the Distaloy 4600A and 4800A grades form one of the cornerstones of our high performance material development program. They can be quench-hardened to achieve properties that are superior to existing nickel-molybdenum prealloys - see Figure 8 (15). They are also, with the correct presintering temperature, capable of being double pressed to higher densities than other low-alloy powders - Figure 9 (15).

Nickel and copper additions can be admixed to further enhance the performance of both Ancorsteel 85 HP and Ancorsteel 150 HP - Figures 10 - 11 (16, 17), These results were developed using conventional sintering furnace cooling rates. The materials sinter-harden under accelerated cooling conditions and Ancorsteel 85 HP + 2% Cu + 0.9% graphite has been shown to outperform a similar premix based on Ancorsteel 4600V (1.8% Ni/ 0.5% Mo prealloyed powder) 08).

SEGREGATION AND DUSTING

While admixed powders are the most susceptible to segregation and dusting, prealloyed and partially alloyed powders are also prone to segregation of admixed graphite. This may happen during discharge of the mix from the blender, during powder transfer to the feed hopper of the compaction press, or during transfer of the powder to the die cavity - see Figure 12. Compositional variations that result from these demixing phenomena cause variations in the green and sintered properties of compacts.

ANCORBOND® PROCESSING - A NEW MIXING TECHNOLOGY

In late 1982, encouraged by the favorable outcome of research in Sweden (19), a project was started to resolve the problems of segregation and dusting in premixes by developing a binder treatment during mixing to bond additions to the base powders. The program led to the development of ANCORBOND technology, a proprietary mixing process that uses patented binders (20). The research was carried out in two stages :

- development of an effective binder treatment process
- verification of the parts manufacturing advantages of the resulting product

Rather extensive trials, both in the laboratory and under actual production conditions, indicated that bonded mixes have a very significant potential for reducing variability in the parts manufacturing process (21 - 25). Commercial production of ANCORBOND processed mixes began in the first quarter of 1989.

The difference in flow behavior between a regular premix containing 1% graphite and an ANCORBOND processed mix is illustrated in Figure 13. The stable flow of the latter compared with the erratic flow and dusting of the regular premix is quite apparent. The improved flow rate and better die filling characteristics were particularly noticeable during early market trial (25).

FERROUS P/M MATERIALS FOR HIGH PERFORMANCE PARTS

ANCORBOND processing is important not only for the potential it offers for improving productivity and reducing variability in the manufacture of P/M parts but also for the opportunities it offers for new alloy development and the range of fine particle additives that can be used. It has great promise as part of a systems approach to achieving increased P/M part densities without the need to resort to double press/double sinter techniques.

A systems approach is required to optimize each stage involved in the production of a P/M part. There are three main steps involved:

- Mixing
- Compaction
- Sintering

Mixing

This phase of the operation has been covered extensively in the previous sections of this paper. ANCORBOND processing offers the potential for combining the best features of prealloyed, partially alloyed, and admixed materials to optimize the raw materials phase of the parts making process. The way the powder is constituted will significantly influence the nature of the porosity and the microstructure of the finished part. Correct selection of the alloy constituents and the added lubricant is vital to the second stage of the process.

Compaction

Powder characteristics that affect the compaction process include:

- Apparent density
- Flow/fill characteristics
- Particle hardness
- Particle size
- Compressibility
- Green Strength

The effect of mixing time on the apparent density of Ancorsteel 1000 based premixes containing various types and quantities of lubricant is shown in Figure 14. The choice of lubricant clearly has a significant effect on the apparent density of the powder. Higher apparent density leads to reduced die fill height and less punch motion during compaction. However, increased apparent density is often synonymous with lower green strength and a balance has to be effected between the two. ANCORBOND processing results in slightly higher apparent density and better filling of the die cavity while retaining similar green strength.

High lubricant contents severely restrict the density to which a material can be compacted. The effect of lubricant content on the pore free density of compacted powder mixes is shown in Figure 15 where the relative influence of alloying additives and graphite are also illustrated. Lubricant content clearly has the most effect followed by that of graphite.

Alloying additions such as copper or nickel have little or no effect. The pore free density is the maximum density to J which the mixture can be compacted in the die cavity. However, the density of the resulting green compact will be lower than this value due to frictional losses during compaction and green expansion of the compact on ejection from the die cavity. Tool design and compaction sequencing also have a considerable influence on green part density and particular attention has to be paid to these items in any high performance part development program.

Sintering

There are three key influences on part density during the sintering operation:

- Lubricant removal
- Alloying dimensional change (shrinkage or growth)

Not only does the added lubricant affect density during the compaction phase it also influences density during sintering when the lubricant is removed from the compact. This loss of material, without change in volume, reduces the density of the compact.

The way in which the alloy is constituted will determine the extent to which alloying during the sintering operation will alter the density of the compact. This is where the ability to optimize the alloy through ANCORBOND processing to achieve the correct balance between prealloyed, partially alloyed, and admixed additions will be a key factor. This approach has been successfully applied to the production of steering column tilt levers (26, 27).

Higher performance materials will result from reduced levels of porosity (6), and growth during sintering is counterproductive. Some shrinkage during sintering is therefore desired, with overall dimensional change values, with respect to die size, being close to zero.

CONCLUSIONS

The microstructure and performance of P/M parts are directly influenced by the alloying method used to constitute the P/M material. P/M alloys are true-engineered materials and in order to achieve the best combination of strength and toughness in P/M steels it is necessary to optimize the properties of both the inter-particle and the within-particle regions.

The availability of both Distaloy and highly compressible prealloyed powders in combination with ANCORBOND premix technology offers new opportunities for high performance P/M materials development.

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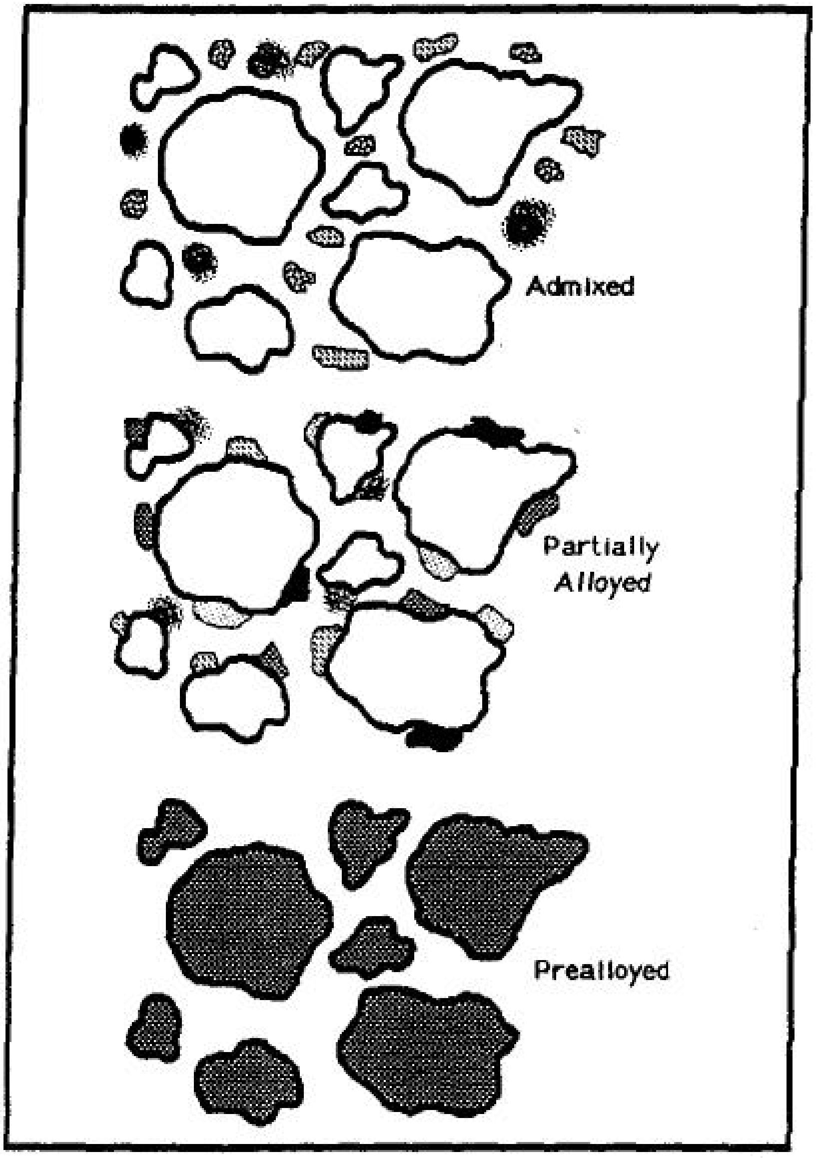


Figure 1 : Alloying methods schematic.

Figure 2 : Stacker crane in Hoeganaes' fully automated, state-of-the-art facility in Milton, Pennsylvania.

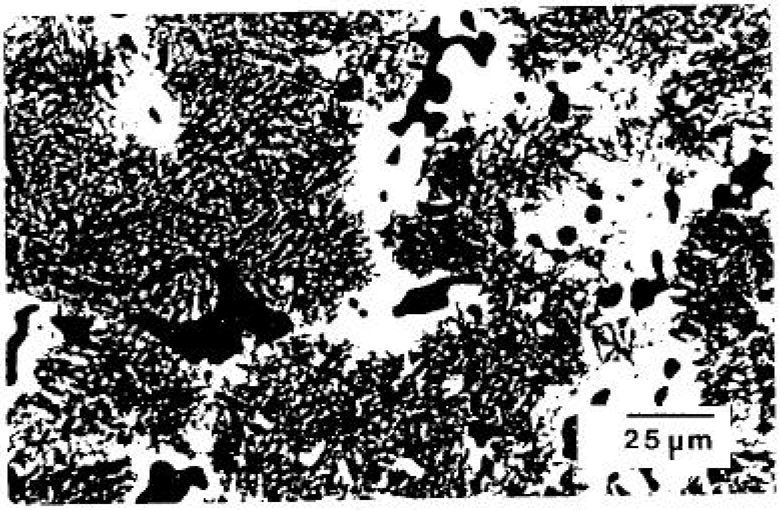


Figure 3 : Photomicrograph of a nickel steel (FN - 0208) sintered at 2050°F, quench-hardened. Etched with a combination of 2% nital/4% picral.

Figure 4 : Photomicrograph of Distaloy 4800A, 0.8% gr., sinter-hardened,37 minutes at 2050 °F, tempered at 375 °F. Etched with a combination of 2% nital/4% picral.

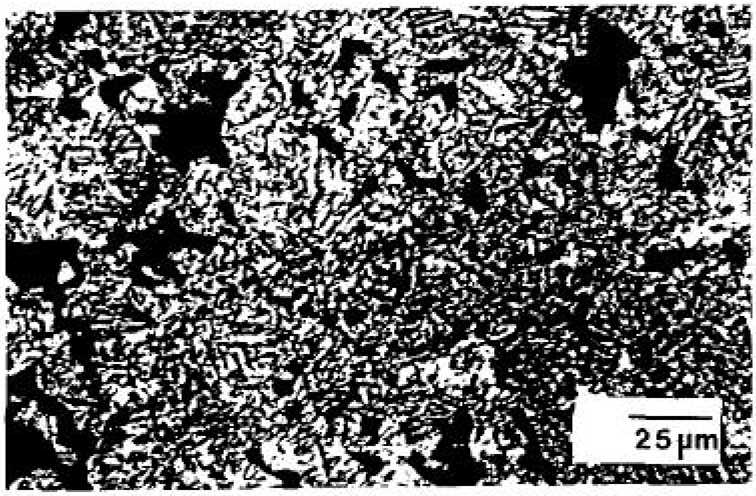


Figure 5 : Photomicrograph of Ancorsteel 4600V, 0.6% gr., sintered at 2050°F, quench-hardened. Etched with a combination of 2% nital/4% picral.

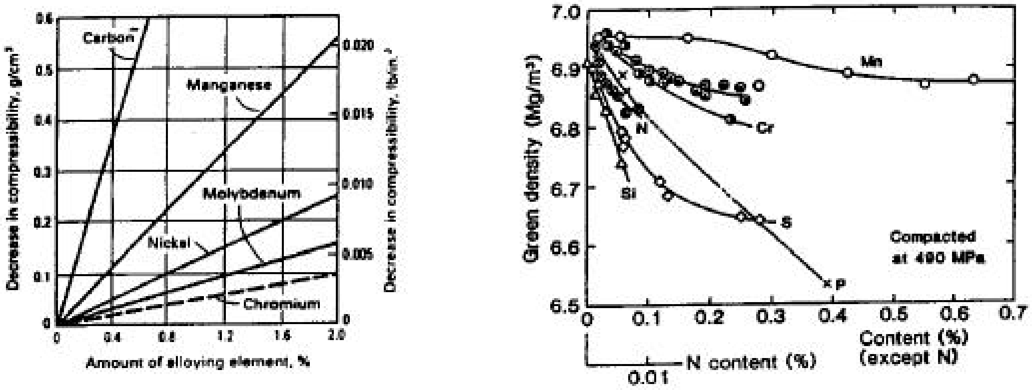


Figure 6 : The influence of alloying and interstitial elements on compressibility (references 13 and 14).

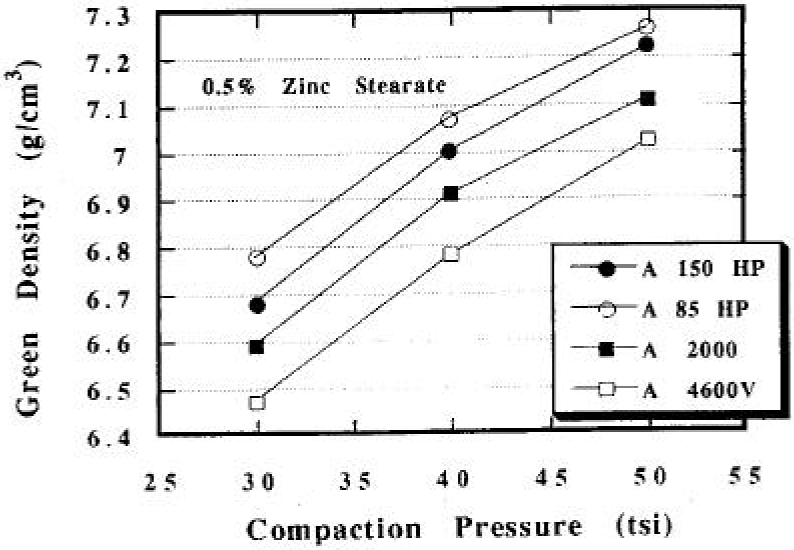
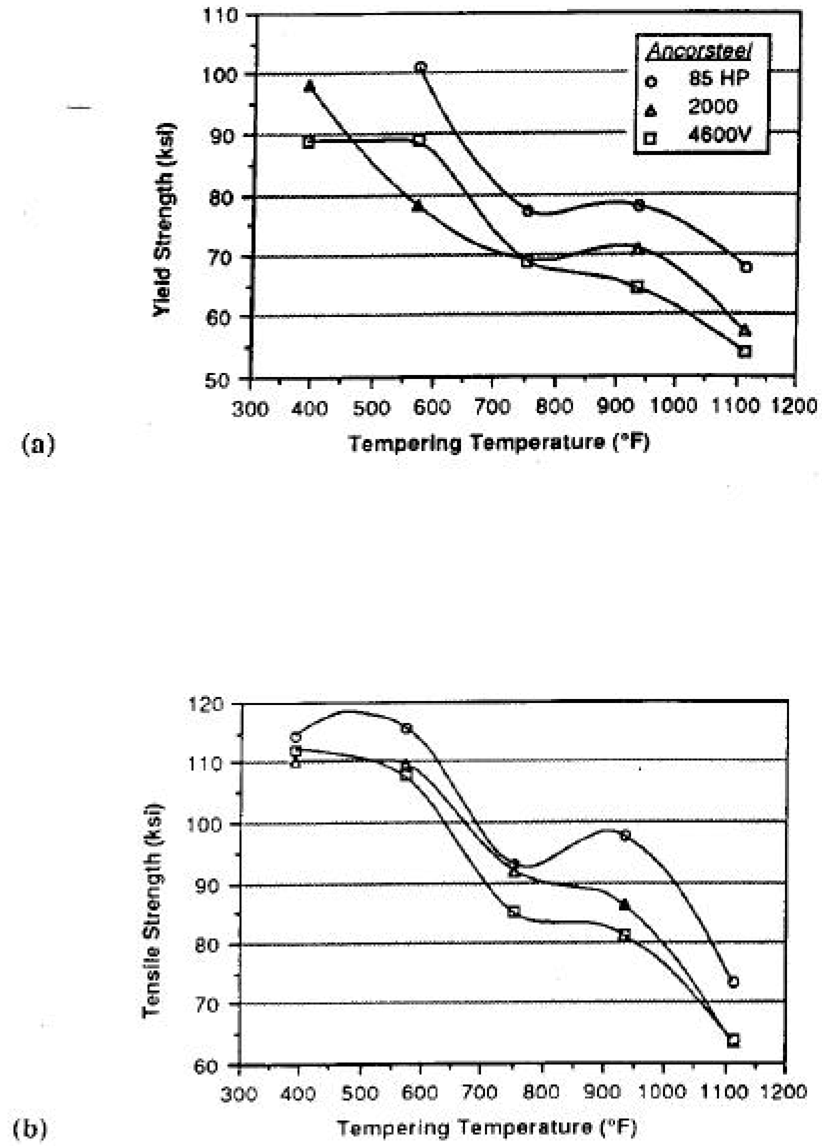


Figure 7 : Compressibility of various low-alloy powders.



igure 8 : Effect of tempering temperature on the quench-hardened yield and ultimate tensile strength of Ancorsteel 85 HP, Ancorsteel 2000, and Ancorsteel 4600V mixed with 0.6% graphite, 0.5% zinc stearate compacted at 40 tsi.

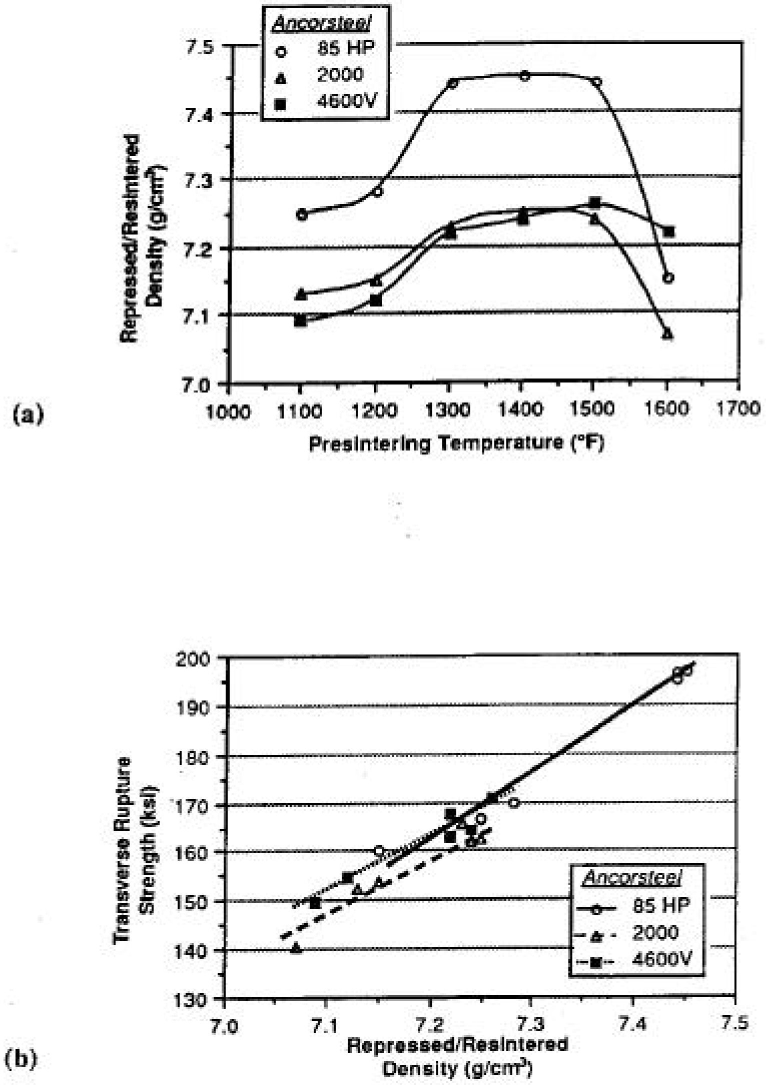


Figure 9 : Presintering response of Ancorsteel 85 HP, Ancorsteel 2000, and Ancorsteel 4600V mixed with 0.6% graphite and 0.5% zinc stearate: a) density after compaction at 45 tsi, presintering at the indicated temperature for 30 minutes in dissociated ammonia, repressing at 45 tsi and resintering at 2050 °F for 30 minutes in dissociated ammonia, b) double pressed and sintered transverse rupture strength.

	A	B	C	D	E	F	G
Nickel (%)	2	0	2	2	4	4	4
Copper (%)	0	2	1	2	0	1	2
Ancorsteel 85 HP	balance	balance	balance	balance	balance	balance	balance

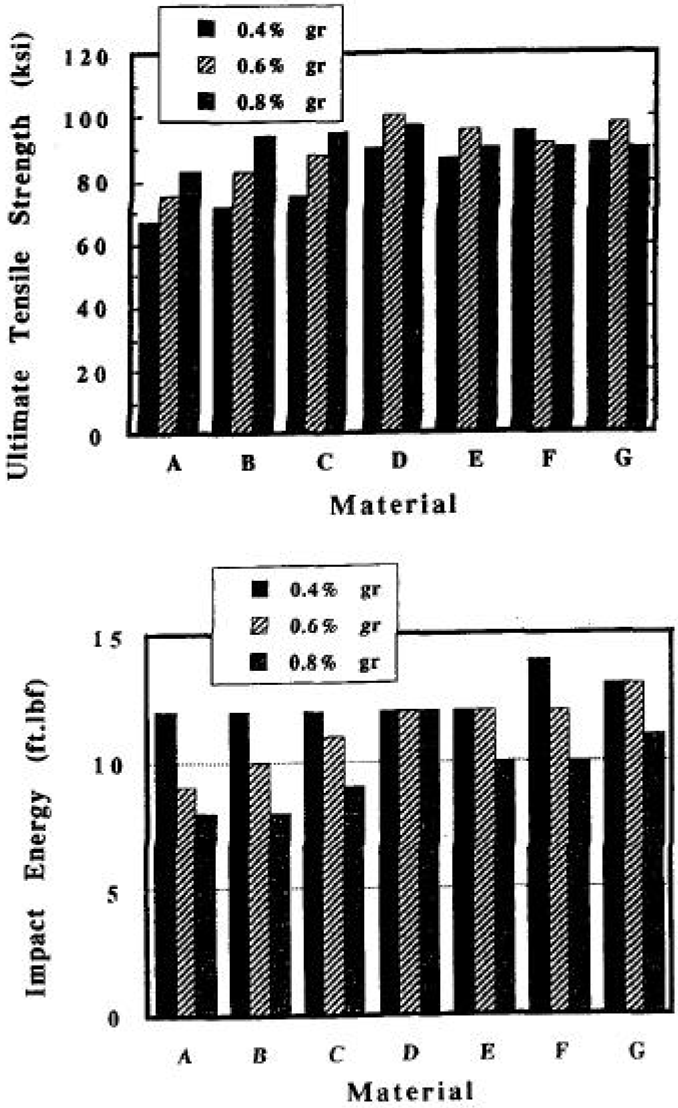


Figure 10 : Tensile and impact properties of Ancorsteel 85 HP based premixes at 7.0 g/cm3. All specimens sintered at 2050 °F for 30 mins. in DA

	A	C	F
Nickel (%)	2	2	4
Copper (%)	0	1	1
Ancorsteel 150 HP	balance	balance	balance

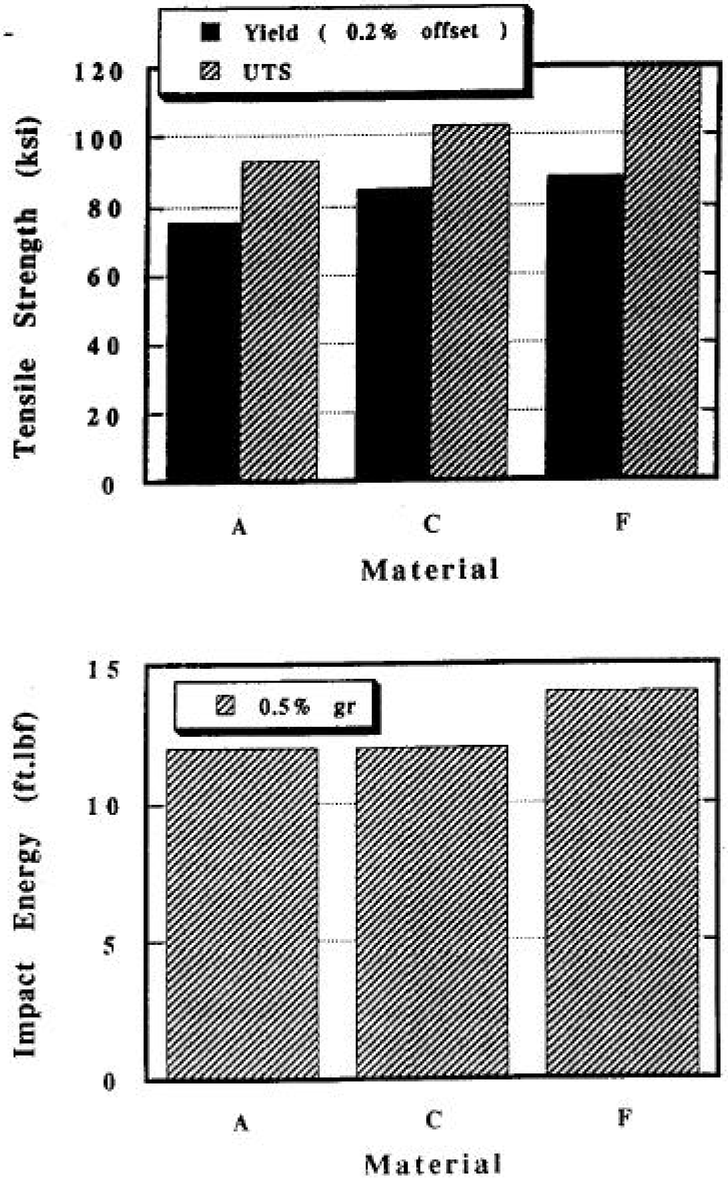


Figure 11 : Tensile and impact properties of premixes based on Ancorsteel 150 HP. All specimens compacted at 45 tsi and sintered at 2050 °F for 30 mins in DA.

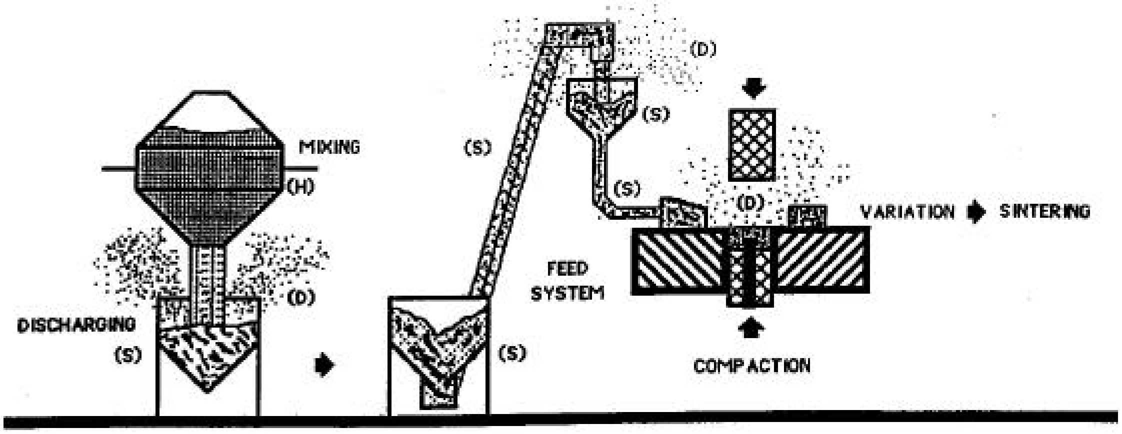


Figure 12 : Segregation and dusting during the P/M process.

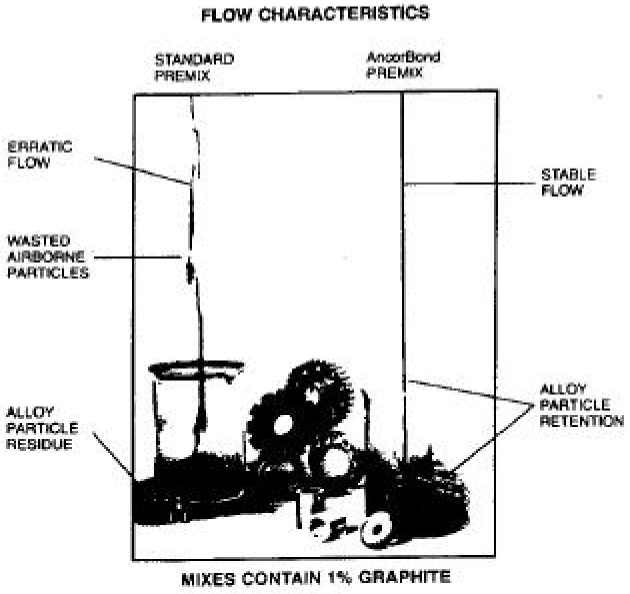


Figure 13 : Flow comparison between a regular premix and a binder treated ANCORBOND premix.

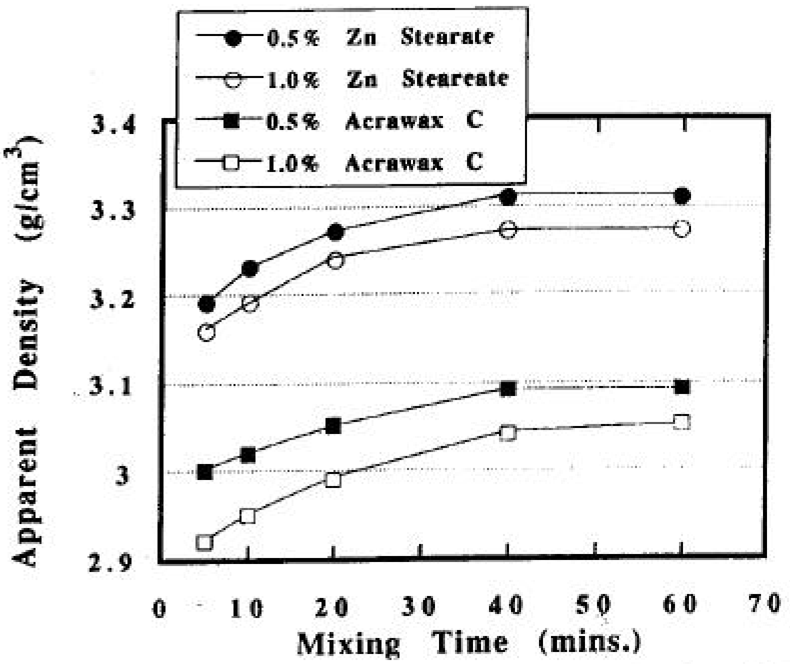


Figure 14 : Effect of mixing time on the apparent density of Ancorsteel 1000 based premixes containing various types and quantities of lubricant.

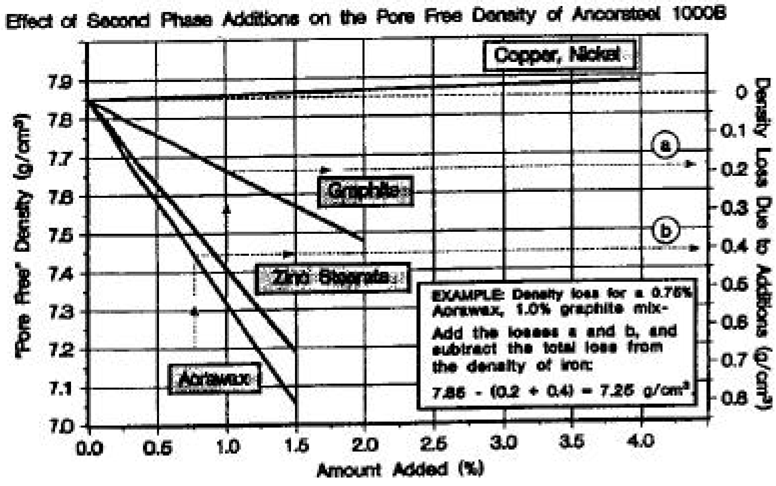


Figure 15 : Effect of premix additives on the pore free density of Ancorsteel 1000B.