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# RECYCLING OF CAST IRON CHIPS BY POWDER METALLURGY[*]

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## *RINGKASAN*

*Penggunaan geram (sisa-sisa pengerjaan) dari besi tuang sebagai bahan baku murah di dalam industri puder metallurgi (logam dalam bentuk serbuk (puder)), kini sedang berkembang untuk membuat produk-produk yang bermanfaat. Di dalam studi ini yang diperhatikan adalah segi-segi teknik dan ekonomi dari proses-proses pembuatan puder.*

*Sifat-sifat mekanis besi tuang kelabu pada dasarnya ditentukan oleh jumlah kandungan grafit di dalam matrik, yang mana kandungan grafit dari besi tuang ini juga mempengaruhi kepada sifat-sifat pudernya.*

*Tulisan ini menguraikan pula tentang pengaruh dari teknik pembuatan puder terhadap: sifat-sifat puder seperti bentuk, besar dan grafit yang terlepas dari matrik dan demikian pula terhadap proses-proses pengepresan dan penyinteran. Didiskusikan pula mengenai pengaruh dari gas yang digunakan untuk proses penyinteran terhadap sifat-sifat produk yang telah disinter.*

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## ABSTRACT

*The utilization of cast iron chips as an alternative cheaper raw material in the powder metallurgy industry is currently undergoing development to produce useful products. The present work is concerned with the technology and economy of such an alternative powder processing technique.*

*The mechanical properties of grey cast iron are primarily determined by the proportion of included graphite in the metallic matrix in which the graphite also affects the properties of powdered cast iron chips.*

*The influences of the processing technique on the powder characteristics such as the shape, the size, the loose graphite as well as the subsequent route of compacting and sintering are described. In sintering, the effects of the protective atmosphere used on the properties of sintered compact are discussed.*

## *Introduction*

Cast iron machining particles (swarf) such as chips, borings or the like is a material which has apparently been proposed from time to time as a source of powder which can be pressed and sintered. The cost is also very low or nil if generated "in house". The swarf is first comminuted to a powder of suitable particle size. This is accomplished by milling and annealing cycle appropriate to the raw material.

This technique is now more preferred, since conventional techniques of remelting and casting of metal waste into ingot moulds may introduce undesirable pollution to the environment due to the burning of some lubricants retained in the chips. Also, accounting to energy savings as generally expected from Powder Metallurgy (P/M) technique, the use of powder metallurgical recycling technique is currently receiving much attention. Moreover, the recent oil crisis has if anything accentuated the need for further research in this field.

The use of the powder metallurgical recycling technique is not merely for the cast iron machining swarf, but it can also be recommended for other machining swarfs. For instance, it is only very recently that the Ford Motor Company's Engineering and Research Staff reported that Ford has developed a process for making iron powder from machining turnings. Researchers have made from chromium-nickel-molybdenum-silicon alloy steel chips using a small pilot set-up at Ford's Manufacturing Development Center in Detroit. A large pilot-line capable of making several thousand pounds of powder monthly will be operating there by the end of 1978. The process consists of cleaning the turnings, followed by shredding, embrittling, grinding, coating, annealing and then screening. It was also reported that powder can be made for approximately 65 per-cent of the current published per-pound price of atomized iron(1).

Chips of many materials especially brittle material such as cast iron can be recycled into powder easily. This is the main reason why the present work focuses only on the recycling of cast iron chips. In addition, wherever a great number of scraps and/or chips are found (e.g. in Indonesia), the use of this technique may be profitable.

## *Experimental procedures*

a. Preparation of cast iron chips.

The cast iron chips were collected from the machining process. The grade of this cast iron was grey with a carbon content around 3.5 %. This cast iron was machined in dry condition on a lathe (turning) machine.

b. Powder preparation.

Of all the machining chips, cast iron chips are the most brittle and can easily be milled to very fine particles. The powder processing methods used include, swing hammer mill, eccentric grinding ball mill (conventional ball mill) and attrition mill. Table 1 presents the kinds of powder that have been processed.

c. Cold compaction.

The cylindrical specimens with a diameter of 10 mm were made by a hand press machine with an allowable compacting load of 7 ton. These specimens were prepared for the green density determination as a function of compacting pressure. Whereas the tensile test specimens were prepared by using a hydraulic press machine (maximum capacity: 100 ton). The tensile test specimens were made according to the MPIF standard with the pressure area: 1.0 sq-in.

d. Sintering.

After compacting, the green compacts of powdered cast iron chips were heated in a protective atmosphere furnace to a relatively high temperature, but below the melting point of the metal powder. Two sintering atmospheres used in this investigation were hydrogen ($H_2$) and argon (Ar).

Table 1. Powders made by different processing methods

| Powder grades | Powder processing method |
|---|---|
| $A_1$ | Chips milled into powder by swing hammer mill. |
| $A_2$ | Powder $A_1$ milled further by eccentric grinding ball mill for 2 hours. |
| $A_3$ | Idem as $A_2$, but with processing time 7 hours. |
| $A_4$ | Powder $A_1$ was added with 25 % iron powder and mixed for 1.5 hours in Turbula machine. |
| $B_1$ | Powder from chips made by swing hammer mill then followed by attrition milling process for 7 hours. The resulting powder was annealed at 650°C for 1 hour under hydrogen atmosphere. |
| $B_2$ | Powder $B_1$ was added with 10 % iron powder and mixed for 1.5 hours in Turbula machine. |
| $B_3$ | Idem as $B_2$ but with iron powder addition of 25 %. |

Note: A and B are grey cast iron with phosphorus content around 0.8 % and 0.1 % respectively.

e. Density measurement.

Green and sintered densities of the specimen were measured by the Archimedean method.

f. Tensile test.

Tensile tests were carried out to measure tensile strength using an Instron machine.

g. Metallography.

All specimens were examined by light microscope after being polished and etched. The etchant used for this grey cast iron was: nital (2 cc $HNO_3$ in 100 cc methylalcohol). In particular cases, the observation of unetched specimen was necessary.

The characteristics of a powder particle e.g. size, shape, surface structure and pore detail were obtained by using a Scanning Electron Microscope (SEM).

## *Experimental results and discussions*

a. Material, chips and powder.

The material was grey cast iron with two different grades of phosphorus content, one at ± 0.8 % and the other at ± 0.1 %. The microstructures are given in figure 1.

The chips made from machining turnings show discontinuity due to the brittle properties of cast iron (see figure 2).

The powder obtained from the chips was processed by different procedures as specified in Table 1 and the morphology of the powder related to the process are presented in figure 3.

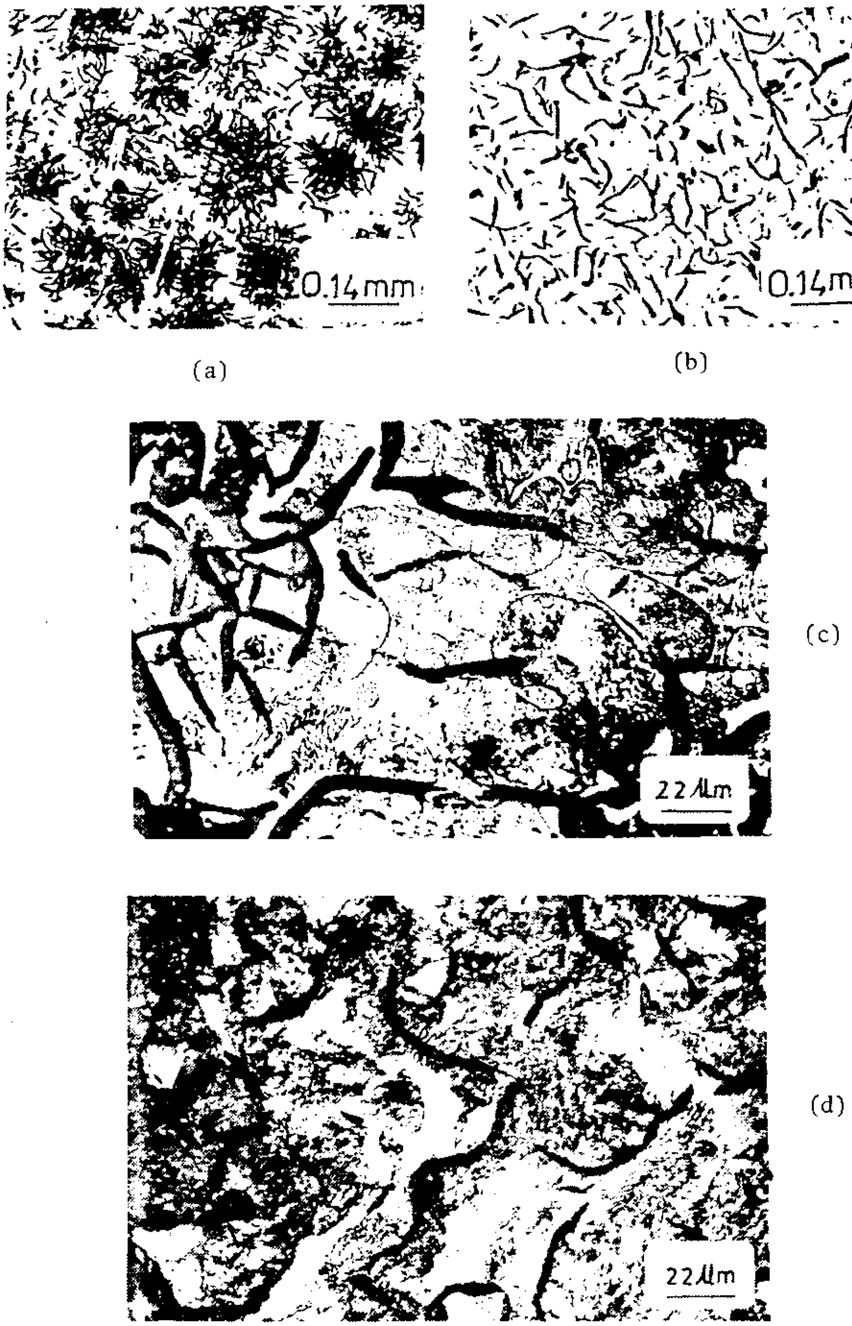
b. Compactibility.

As indicated in figure 3, the particles form should reflect to their compactibilities. As usual, the powder particles with irregular shape should permit good particle interlocking during compacting to provide high green strength. The density gain with increasing compacting pressure for these powders are shown in figures 4 and 5 for different conditions. Here, it should be noted that the density of powder $A_1 \rightarrow A_3$ is lower then powders B for the same compacting pressure. This is due to the fact that the inherent free carbon of the loose graphite of cast iron powder acts as a lubricant for compaction which provides high green density.

c. Sintered strength.

In the sintering process, the particles are bonding together which is determined primarily by the three important parameters i.e. sintering atmosphere, temperature and time. However, the rate of bonding reaction that occurs during sintering could also be influenced by other mechanisms. Experimental results given in figure 6 apparently show that hydrogen as sintering atmosphere gives a higher sintered strength then argon. And figure 6 describes that the increase in processing time of the cast iron powder by the grinding ball mill lowers the tensile strength of the sintered product. Further, let us consider figure 6 as follows:

- If the powdered cast iron chips is only produced by swing hammer mill, the resulting particles are irregular or nodular in shape which permits good particle inter-



(a) (b) (c) (d)

Fig. 1: Grey cast iron

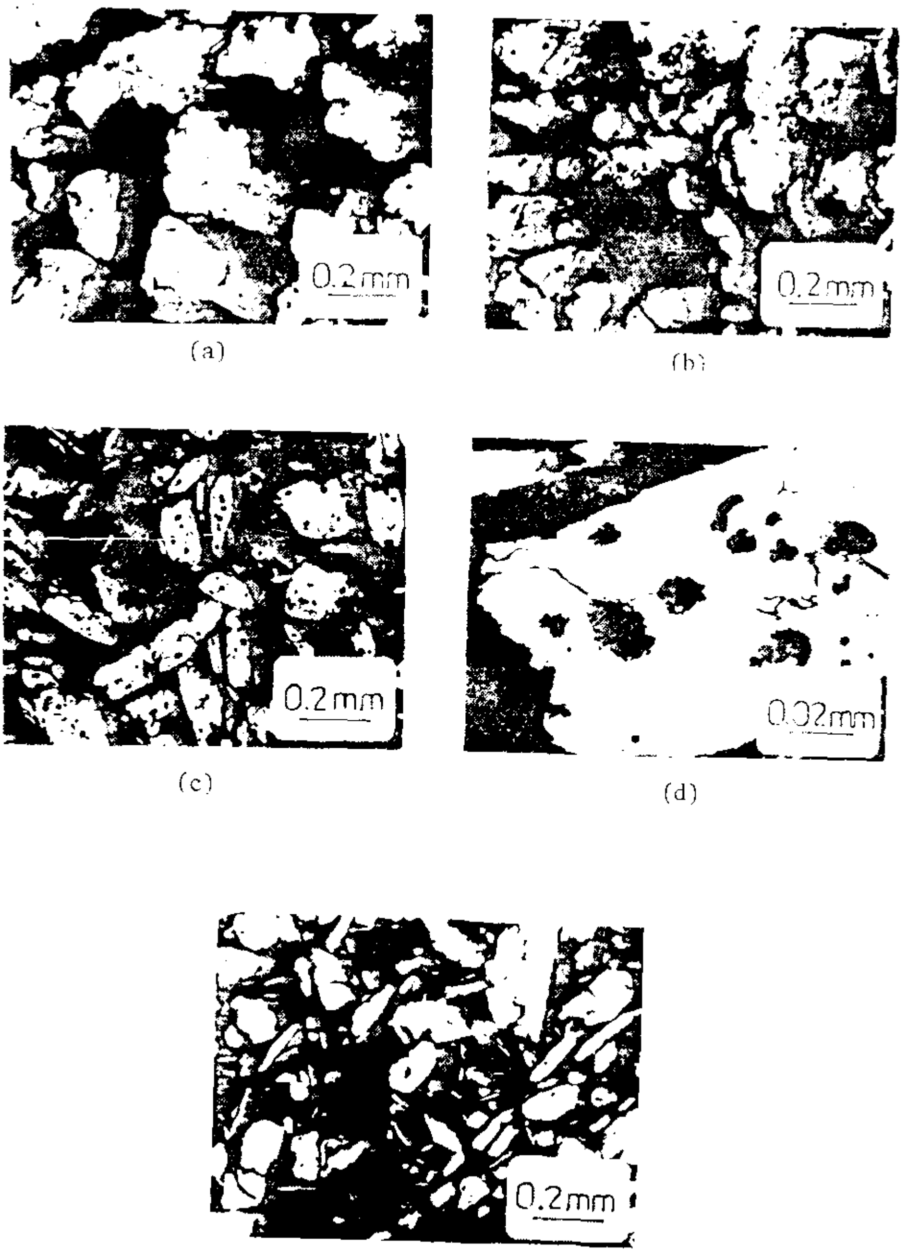
Fig. 1a: Grey cast iron of material for powder A. The graphite feature is rossete grouping type.

Fig. 1b: Grey cast iron of material for powder B. The graphite flake is uniform distributed on the whole matrix but with random orientation.
(Unetched specimens)

Fig. 1c: Grey cast iron with graphite rossete groupings. The microstructure shows pearlite and ferrite.
The white structure with small holes is a eutectic structure of iron phosphide and ferrite, called steadite.
(light nital etch)

Fig. 1d: The matrix structure is almost completely pearlitic, although a few ferrite areas are visible with silicon, etc., in solid solution.
(light nital etch)

Fig. 2: Configuration of grey cast iron chips

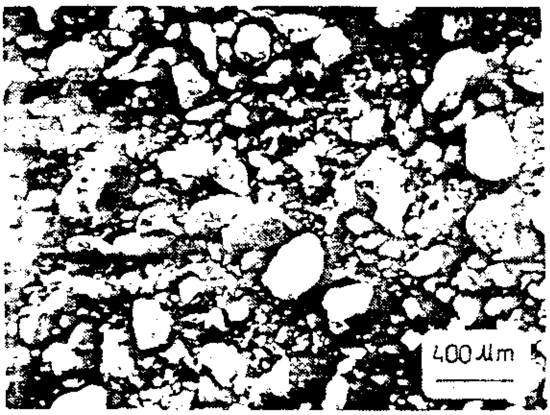


(a) (b)

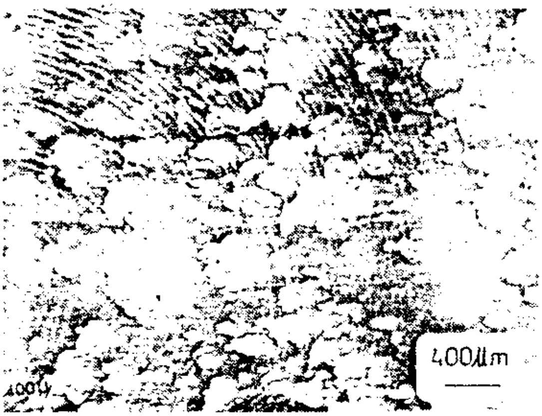
(c) (d)

(e)

Fig. 3: Powder cast iron chip



(f)



(g)

Fig. 3 : Powder cast iron chips.

3a: Grey cast iron powders made by swing hammer mill (Powder $A_1$).

3b: Powder $A_1$, after further processing on grinding ball mill for 2 hours (Powder $A_2$).

3c: Chips milled into powder by swing hammer mill, then continued by attrition milling process for 7 hours.

3d: As in fig. 3c, but at higher magnification.

3e: The resulting powder (as in fig. 3c) was annealed at 650°C for 1 hour under hydrogen atmosphere. Then the annealed powder was mixed with 10% iron powder.

3f: Scanning electron micrograph of powder $A_1$ (made by swing hammer milling technique).

3g: Scanning electron micrograph of powder $B_1$ (see Table 1).

locking during compacting and provides higher green and sintered strength.

- By processing further with the grinding ball mill the particle size decreases which can be followed by shredding of the lamellae graphite from their matrix to become inherent free carbon. The amount of this free carbon is sufficient to gain the compactibility, especially for lower compacting pressure (figure 4). But after the compacting pressure exceeds a value of 7.5 ton/ $cm^2$, the green density of powder made from the swing hammer mill (powder $A_1$) improves favourably and provides a higher green density of the compact. The restriction of sintering reaction of the compacts of powders of $A_2$ and $A_3$ might also be affected by the surface stresses that occur on the primary particles during further grinding process.
- Hydrogen can reduce the iron oxide and improves the sintering reaction, whereas argon only acts to prevent the oxidation during sintering. Argon chemically acts to promote graphitization whereas hydrogen seems to stabilize carbides. This is another reason why argon as sintering atmosphere provides lower sintered strength than hydrogen. The microstructures of sintered specimens are presented in figure 7.

The powder which was processed by the swing hammer mill followed by attrition milling exhibits a very low green strength. This was caused by the excessive amount of loose graphite and iron oxide present in the powder. The annealing treatment was performed for this powder at 650°C for 1 hour under hydrogen atmosphere. It was possible to handle the compacts after annealing and surprisingly they show higher green density than the compacts of powders A. But the tensile strength of sintered specimens of powders B are much lower than the sintered strength of specimens from powders A as shown in figure 8. By the addition of 25 % iron powder, the sintered strength increases up to 11.62 $kg/mm^2$. The microstructures of the sintered specimens of powder B are given in figure 9. From figure 9, it becomes clear that the excess of inherent free carbon present in the powder causes an interlinked network of fine graphite lamellae and this is one of the reasons why the material is weak.

A recent paper(2) shows that the tensile strength of sintered cast iron specimen is apparently very much sensitive to an increase in the sintering temperature. For instance, a green compact of 8 $ton/cm^2$ compacting pressure, sintered at 1100°C for 1 hour under hydrogen atmosphere

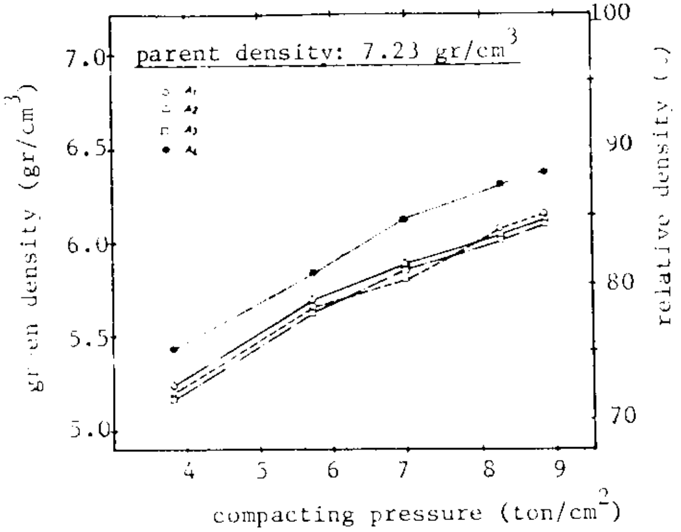


Fig. 4: Green density vs compacting pressure
(Powders A)

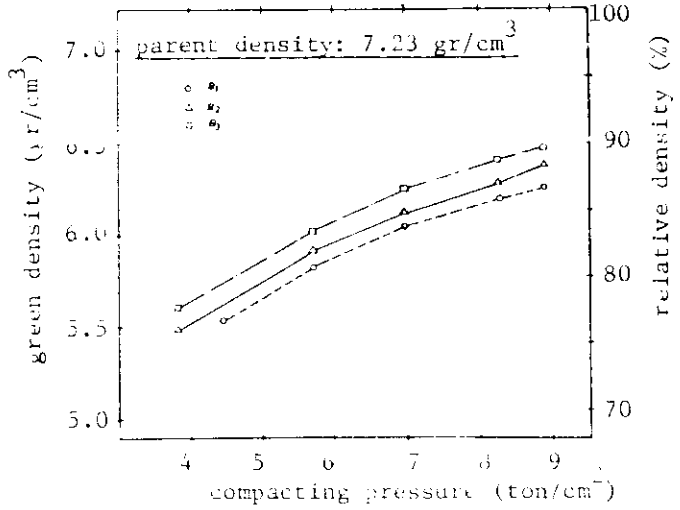


Fig. 5: Green density vs compacting pressure
(Powders B)

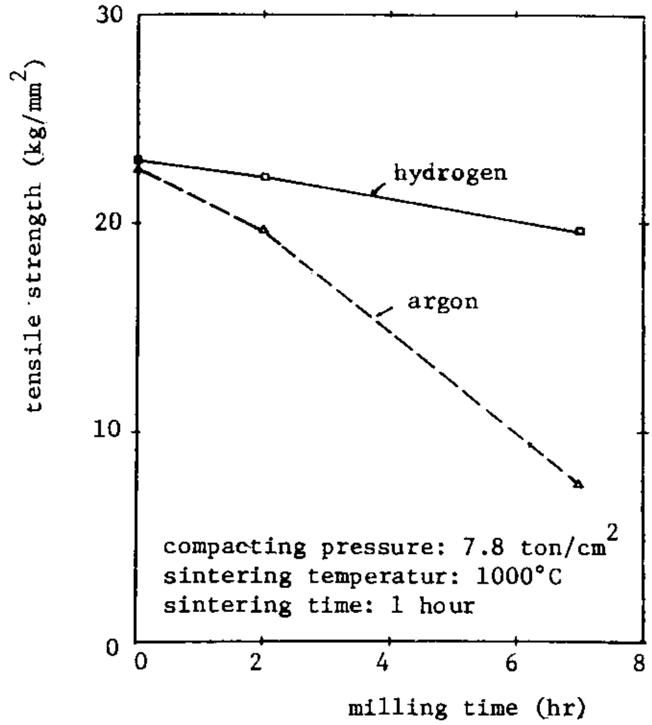


Fig. 6: Tensile strength of sintered specimens as a function of milling time (Powder A).

(a)

(b)

Fig. 7

Fig. 7a: Sintered specimen of powder $A_1$ (7.8 ton/cm$^2$, $H_2$, 1000°C - 1 hour).

Fig. 7b: Sintered specimen of powder $A_1$ (7.8 ton/cm$^2$, Argon, 1000°C - 1 hour).

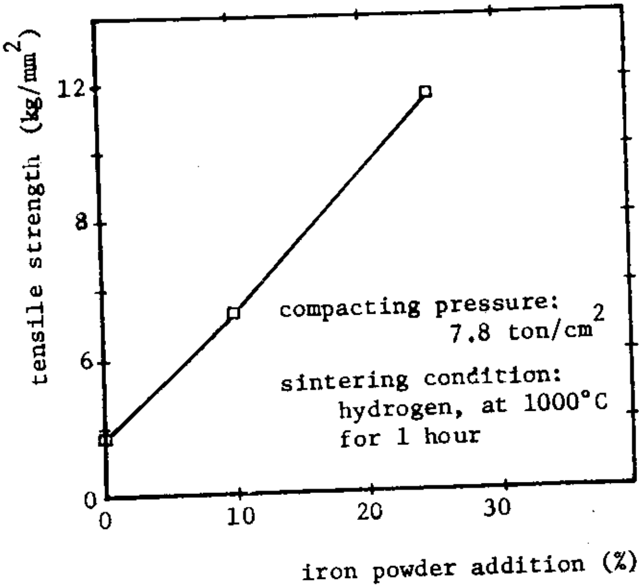
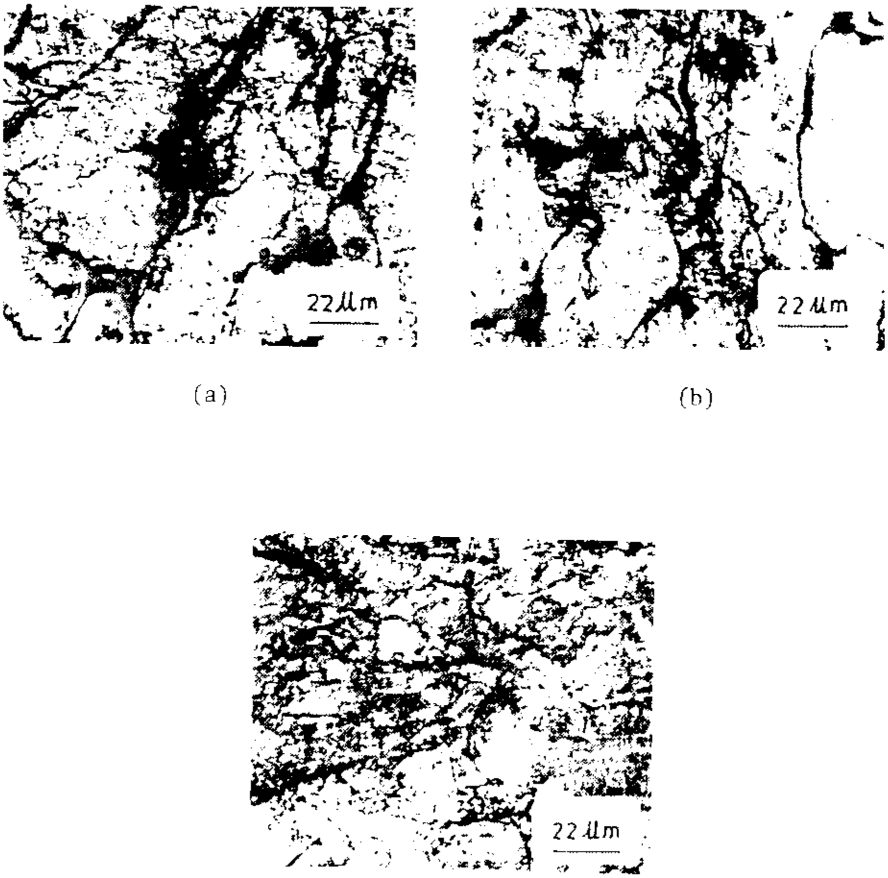


Fig. 8: Tensile strength of sintered specimens made from powders B as a function of per-cent iron powder addition.



(a)

(b)

(c)

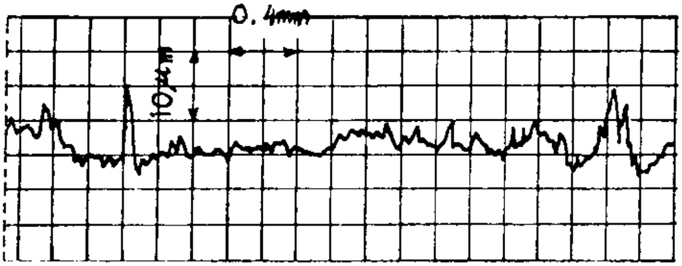
Fig. 9 : Sintered specimens of powders B (7.8 ton/cm$^2$, $H_2$, 1000°C - 1 hour).

9a: Powder $B_1$

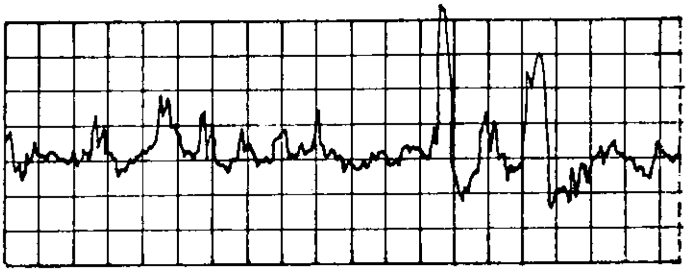
9b: Powder $B_2$

9c: Powder $B_3$

Fig. 10: Microstructure of sintered specimen (7.8 ton/$cm^2$, $H_2$, 1100°C - 1 hour).



a. 1100°C



b. 1150°C

Fig. 11: Surface roughness of sintered specimen (7.8 ton/$cm^2$, $H_2$).

has provided up to 35 $kg/mm^2$ of tensile strength. It is also clear that the tensile strength is higher than the parent cast iron at sintering temperature above 1100°C even though the sintered specimens are porous. This may be because of a more homogeneous structure due to crushing and because the temperature of sintering is close to the melting point which may cause a transformation of flaked graphite into spheroidal shape as shown in figure 10 of the present work.

It was also noted that the sintering temperature however, has a limitation because higher sintering temperature increases the surface roughness of the product as shown in figure 11.

## *Conclusions*

It has been shown that the powdered cast iron chips produced by using only swing hammer milling technique provides a higher sintered strength than the combination of a swing hammer and a grinding ball mill or an attrition mill. Thus, it can be applied in practice for making mechanical sintered parts with good quality and in an economical way. Cast iron turnings can be recycled into useful components by powder metallurgical technique, but it can also serve as a new base powder for the production of new materials.

In principle, further improvement could be expected if the particle size is further reduced. However, the finer the particles of cast iron powder, the greater the tendency of the graphite to be present as free flakes which then tends to decrease the tensile strength of the sintered parts. So, this does not offer advantages either mechanically or economically. However, if this problem is solved by removing the free carbon from the powder, there will be a still greater advantage of introduction of P/M recycling of cast iron chips.

## *Acknowledgement*

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