DEVELOPMENT OF SINTERED IRON DRIVING BANDS

R. P. KHANNA* & N. T. GEORGE
Defence Metallurgical Research Laboratory, Hyderabad

(*Received* 31 *July* 1973; *revised* 6 *December* 1973)

The present investigation reports some detailed studies carried out on the development, testing and proving of sintered Iron Driving Bands. Sintering studies on two different types of iron powders together with a few *Fe-Cu* compositions have been made and based on the results thereof, parameters for developing iron driving bands have been standardised. The results obtained clearly demonstrate that substitution of copper by sintered iron is highly practicable alternative.

The development of sintered components such as bearings, filters, electrical contacts, hard metal tools, magnets, weapon parts etc. by powder metallurgical techniques has contributed significantly to the progress of engineering, electronic and defence industries. The fabrication of components to exacting specifications viz., close tolerance of dimensions, densities and mechanical properties, is a major achievement of powder metallurgy. Powder metallurgical technique was attempted in the Defence Metallurgical Research Laboratory to develope substitutes of electrolytic copper bands used in artillery shells by sintered iron bands. This work could be of importance to defence production, since the copper resources of the country are meagre and the requirements of copper for defence equipments are mainly met by imports. It might be of interest to mention here that quite a few technologically advanced countries like USA, USSR, Germany have already switched over partly to sintered iron components in their ammunition in place of copper components[1—4].

This paper gives an account of the development of iron driving bands based on sintering studies on two different types of iron powders together with a few *Fe-Cu* compositions.

This development programme was divided into three phases viz.,

(*a*) The establishment of correct sintering parameters.

(*b*) Application of results obtained from (*a*) to the development of annular rings exhibiting high ductility.

(*c*) Trial production of ammunition in which copper bands were replaced by sintered iron bands and firing trials for study of ballistic performance.

EXPERIMENTAL PROCEDURE

Material Characteristics

The materials used in this investigation consisted of two types of iron powders and electrolytic copper powder. Iron powder *Fe* A, was prepared in the laboratory from mill scale by ball milling and reduction in H_2 atmosphere at 900°C. Iron powder *Fe* B, was supplied by M/s. Hoganas Limited, Sweden. Copper powder was prepared in the laboratory electrolytically from copper sulphate solution and was annealed in hydrogen at 450°C. The chemical analyses of these powders are given below:

	Fe%	*C*%	*Mn* %	*Si*%	*P*%	*S*%	*Cu*%	*Zn*%	O_2%
Fe A >	98·8	0·05	0·4	0·15	0·01	0·01	—	—	0·4
Fe B >	98·8	0·02	0·15	0·20	0·015	0·015	—	—	0·3
Copper	0·005	0·01	0·005	0·05	—	—	99·5	0·03	0·25

The average particle sizes of these powders were determined on a Fisher Sub-sieve Sizer apparatus while apparent densities were measured by Hall's Apparatus as per ASTM Specifications. The values thus determined along with details of particle shape of the powders are given below :

Powder	Average particle size (μm)	Shape	Apparent density (gms/cc)
Fe A	15	Irregular	2·5
Fe B	13	Irregular & spongy	1·8
Copper	8·8	Dendritic	1·75

* Presently working at Chief Inspectorate of Military Explosives, Kirkee, Poona—411003.

The iron powder *Fe* A was waxed and compacted into 39 mm × 12 mm × 12 mm rods and sintered at 1150°C for varying periods in hydrogen atmosphere. The UTS values of compacts obtained, are presented in Table 1. It is clear from the Table that sintering at 1150°C for 4 hours gave satisfactory values of tensile strength. Compacts made from *Fe* B powder were also sintered under the same conditions. Table 2 illustrates the physical and mechanical properties of green and sintered *Fe* A & *Fe* B samples compacted at various pressures. *Fe* A-*Cu* compositions containing varying amount of copper viz., 1, 2, 4, 5 and 10% were

TABLE 1

Fe A POWDER PRESSED AT 20 TSI SINTERED AT 1150°C IN HYDROGEN ATMOSPHERE

Sintering time (hr)	Density (gms/cc.)	UTS	
		TSI	PSI
1	5·82	4·8	10750
2	5·83	5·6	12540
3	5·84	6·04	13530
4	5·86	7·7	17250

TABLE 2

Physical & mechanical properties of green and sintered *Fe* A & *Fe* B samples at various pressures

Powder	Compacted at TSI	Green density (gms/cc)	Sintering temp. (°C)	Sintering time (hr)	Sintered density (gms/cc)	Hardness (VPN)	UTS (PSI)	E on 1″ (%)
Fe A	15	5·51	1150	4	5·58	28	12500	2·5
	20	5·82	1150	4	5·86	32	16500	3
	25	5·99	1150	4	6·04	35	18400	3·5
	30	6·33	1150	4	6·36	42	22400	4
Fe B	15	5·40	1150	4	5·45	27	11500	5
	22	5·70	1150	4	5·75	30	16500	6
	28	6·03	1150	4	6·08	34	21000	8
	35	6·42	1150	4	6·45	45	24000	10

TABLE 3

Fe A-*Cu* SYSTEM COMPACTED AT 20 TSI AND SINTERED AT 1150°C/4 HOURS

Cu (%)	Density green (gms/cc)	Sintered density (gms/cc)	UTS		E on 1″ (%)	Hardness VPN
			TSI	PSI		
X	5·82	5·86	7·6	17020	4	32
1	5·86	5·96	9·8	22000	3	56
2	5·93	6·05	11·28	25300	3	64
4	6·04	6·13	14·8	33000	2·5	79
5	6·08	6·18	16·5	37000	2·5	88
10	6·15	6·32	20·8	46200	1·5	105

studied after mixing the two powders together in a ball mill for 12 hours and then compacting and sintering as mentioned above. The sintering characteristics of *Fe* A-*Cu* compositions are presented in Table 3.

Fabrication of Annular Rings

The results (Tables 1—3) were applied to 40 mm I. D. annular rings. The die and the plungers required for compacting rings are shown in Fig 1. In order to obtain the best combination of mechanical properties viz., UTS, hardness, ductility, etc. on annular rings, the powders were compacted into 4 different density ranges as given below :

(i) 5.30 to 5.59 gm/cc
(ii) 5.60 to 5.89 gm/cc
(iii) 5.90 to 6.19 gm/cc
(iv) 6.20 to 6.49 gm/cc

The rings pressed from *Fe* A, *Fe* B and *Fe* A-*Cu* (1 to 2%) were sintered at 1150°C for 4 hours in hydrogen atmosphere.

Testing of the Rings

A special type of pulling Jig was fabricated to exert even tension on both the sides while testing UTS property in respect of these rings on the universal testing machine.

Percent elongation on ring circumference was tested by using a standard tapered mandrel (taper 0·5 mm/25 mm) and allowing ring to move across the mandrel from its smaller to its larger cross-section at the rate of 25 mm/mt, till a crack was produced in the ring. The percent elongation was calculated as

$$\frac{ID_2 - ID_1}{ID_1} \times 100$$

where ID_1 is the initial internal diameter and ID_2 is the final internal diameter.

Compression test was conducted by positioning the ring on a small hydraulic press and applying a small load gradually in a direction perpendicular to its axis and observing the compressed internal diameter at the time, the ring cracked. (Fig 2 shows a pair of sintered and compressed rings).

RESULTS AND DISCUSSION

The physical and mechanical properties of any material on sintering are largely dependent upon the characteristics of the starting powder or mixes (if more than one powder is involved) i.e., particle size, shape, nature, distribution, chemical purity, apparent density, compacting pressure and sintering parameters. In the present study, the two *Fe* powders had particles of almost similar average sizes and shapes. *Fe* A powder consisted of irregular particles while *Fe* B powder particles were irregular and spongy. *Fe* A powder had higher apparent density indicative of better particle distribution, while *Fe* B powder showed lower apparent density due to bulky and porous character of its particles. This is clear from Table 2 which shows that higher initial pressures were used to compact *Fe* B powder to approximate it to the same green densities as obtained for *Fe* A.

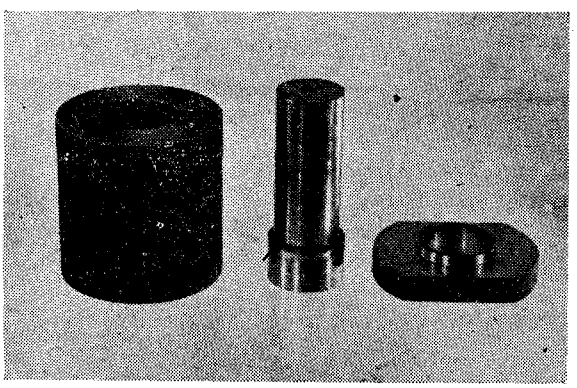

Fig. 1—Die set used for compacting 40 mm I.D. annular rings.

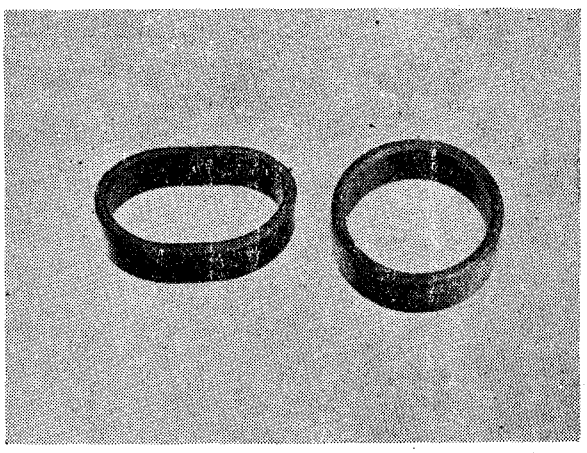

Fig. 2—40 mm dia sintered rings before and after undergoing compression test.

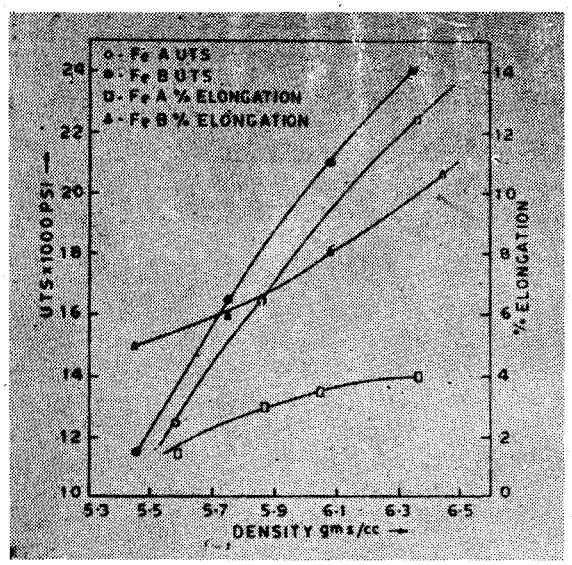

Fig. 3—Tensile properties Vs Density.

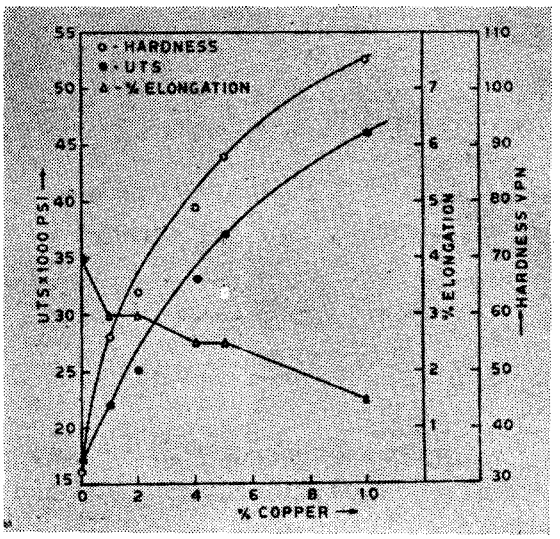

Fig. 4—Sintering Characteristics of *Fe* A-*Cu* compositions sintered at 1150°C in liquid phase of copper.

Studies were initially conducted on *Fe* A powder alone to establish sintering temperature and time in order to achieve optimum mechanical properties. A sintering temperature of 1150°C was considered adequate but sintering time was varied to study its effect on mechanical properties. Table 1 shows UTS values for these samples. The sintering conditions thus standardised were extended to other powders. Fig 3 gives the plot of tensile properties versus density for *Fe* A and *Fe* B samples. It is observed that UTS curves follow a similar trend in both the cases i.e. increase in UTS with increase in density with the difference that *Fe* B compacts exhibit relatively higher values. This is expected because spongy particles of *Fe* B powder on compaction, provide relatively large area of contact. This inturn produces stronger adhesion on sintering. Fig 4 further shows higher amount of ductility for *Fe* B samples i.e. 5 to 10 per cent elongation while *Fe* A samples exhibit low elongation values i.e. 2·5 to 4·0 per cent. This could be ascribed to the presence of rounded porosity which ensures better distribution of stresses in *Fe* B samples. The increase in hardness obtained in both types of specimens corresponds to the increase in densities and UTS as expected.

Fig 4 shows the sintering characteristics of *Fe* A-*Cu* compositions sintered at 1150°C i.e. in liquid phase of copper. There is a considerable increase in UTS value after addition of even small amounts of copper i.e. 1 or 2 percent and this trend is maintained upto 10% copper content without appreciable densification. The marked improvement in tensile strength with the addition of copper can be explained largely due to the effect of liquid copper on the cohesion between the iron particles. Copper wets the surface of iron particles and establishes better *Fe-Fe* contact and makes the pores rounded.

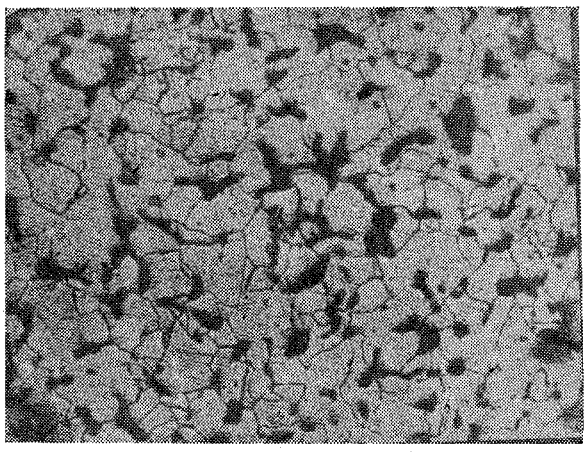

Fig. 5—Pure ferrite grains with inter-connected porosity after sintering *Fe* A at 1150°C for 4 hours (X 200) etchant : 1·5% nital solution.

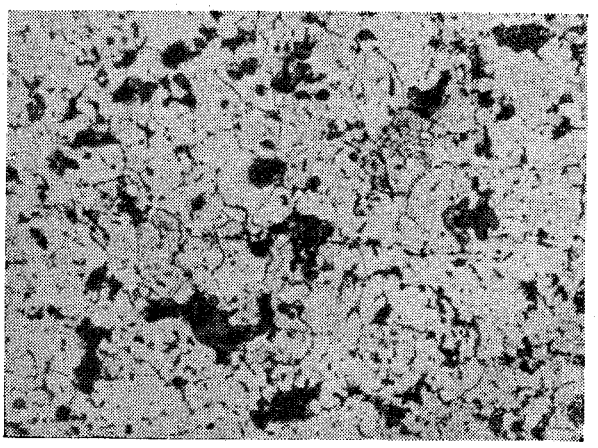

Fig. 6—Ferrite grains with rounded pores after sintering *Fe B* at 1150°C for 4 hours (X 200) etchant : 1·5% nital solution.

TABLE 4

MECHANICAL PROPERTIES OF SINTERED *Fe* A, *Fe* B & *Fe* A-*Cu* RINGS SINTERED AT 1150°C

Powder	Sintered density	Hardness	UTS	E on Band (%)	Compression test :— 40 mm I.D. reduced to (mm)
	5·58	28	12200	1·5	39
	5·86	33	17000	1·8	39
Fe A					
	6·04	35	18200	1·8	39
	6·36	42	22000	2	38·5
	5·45	27	11700	5	28
	5·75	31	16300	6	26
Fe B					
	6·08	35	20500	6·25*	25
	6·44	45	23700	6·25*	25**
Fe A-*Cu*					
99 1	5·96	56	20600	1·5	39
98 2	6·05	61	24800	2·5	39

*Denotes the rings passed over completely the 6·25% bigger dia. mandrel without cracking.

**Denotes the ring did not crack.

Photomicrograph (Fig 5) of sintered *Fe* A specimens shows pure ferrite grains with inter-connected pores which have rather sharp boundaries. Photomicrograph (Fig 6) of *Fe* B specimens shows ferrite grains with rounded pores. Photomicrograph (Fig 7) of *Fe* A-*Cu* specimens shows copper rich phase in addition to that of ferrite phase with rounded pores. In both *Fe* B and *Fe* A-*Cu* specimens the structure obtained imparts higher tensile strength but the ductility is definitely better when the ferrite phase is free from copper.

It is apparent from the above discussion that *Fe* B powder is suitable for driving bands on account of its higher ductility in comparision to *Fe* A and *Fe* A-*Cu* compositions. This was further confirmed by preparing 40 mm annular rings with all the three powders and determining their mechanical properties especially per cent elongation on ring circumference and flattening characteristics under compression. Table 4 tacitly illustrates that the ductility of *Fe* B compacts is decidely superior to other two powders.

The above conclusions have been successfully applied to the development of sintered iron driving bands which are separately discussed in the next section.

Development of Sintered Iron Driving Bands

To study the effect of density on the mechanical and ballistic properties of the driving bands, 100 rings are prepared from *Fe* B powder and these were classified into 4 different density groups as follows :

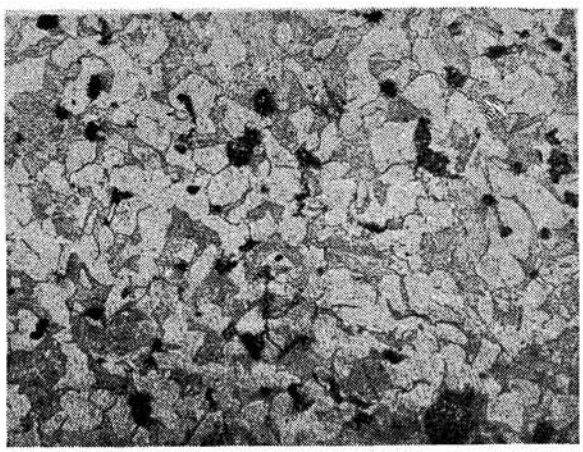

Fig. 7—Ferrite grains with rounded pores and a large region of *Fe-Cu* phase after sintering *Fe-Cu* (4% *Cu*) at 1150°C for 4 hours (X 500) etchant : 1· 5% nital solution.

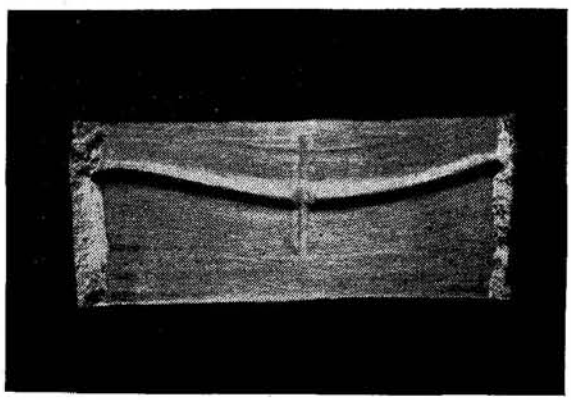

Fig. 8—Impression of the groove on the driving band after pressing and the lines of flow of the material into the undercut.

Lot No.	Density gms/cc	Quantity
1	5·4 to 5·5	5
2	5·7 to 5·8	39
3	6·05 to 6·15	25
4	6·4 to 6·45	31

After impregnation with wax these were pressed on to HE shells using a 12 jaw radial press. The bands, after mounting, were machined to proper form and size. A few bands were chiselled out of the shells and the impression of the groove on the bands was observed. Fig 8 shows the impression of the groove on the band and the lines of the flow of the material into the undercut. The material flowed very well and spread out on application of radial pressure, just like copper. An increase in density of the order of 10—11% was observed. After banding, the hardness of bands increased to the values indicated below :

Lot No.	Initial hardness VPN	Hardness after banding VPN
1	27	60
2	31	70
3	35	80
4	45	90

Ballistic Properties

100 HE shells after banding with sintered iron rings belonging to the density groups mentioned above were filled inert and fired. Service shells also were fired in the same gun for comparison of performance. The average values of range, muzzle velocity and chamber pressure recorded for sintered iron and copper bands showed that there is a marked similarity in the ballistic properties of the two materials. It was found from the trials that medium density rings behave similar to copper rings. They were work-hardened moderately to values similar to those of copper rings during pressing as well as firing. However, the performance of low hardness (low density) rings was found to be unsatisfactory.

CONCLUSION

From the results achieved during the trials, it can be concluded that substitution of copper by sintered iron is practicable. It has also been found that the density required for the sintered material is around 5·6 gm/cc. These medium density sintered iron rings are not likely to cause undue wear on gun barrels since they are only moderately work hardened during banding and firing.

The work has been useful in exploring the possibility of substituting copper and its alloys by sintered iron in other weapon components also. It might be mentioned here that the authors have successfully developed 3″ dia sintered iron ring glands as substitutes for bronze graphite ring glands used at present in the Aden Gun Assembly.

The attempts of the authors to use iron powder produced indigenously namely *Fe* A and its modifications for making sintered iron driving bands have been only partially successful and investigations to develop indigenously a powder similar in characteristics to that of *Fe* B will have to be progressed in future.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. R.V. Tamhankar, Director, Defence Metallurgical Research Laboratory, Hyderabad for his constant encouragement in this work and Superintendent, P & EE, Balasore for arranging the firing trials and supplying the results thereof.

REFERENCES

1. Sintered Iron and Steel Components, BIOS Final Report No. 595.

2. Production of Iron Powder and Sintered Iron Driving Bands in Germany, BIOS Final Report No. 1323.

3. Sintered Iron Shell Rotating Bands FIAT Final Report No. 979.

4. IVORY, W., Special Report No. 38, *J. Iron and Steel Institute*, **157** (1) 1947, pp. 203-8.