



## EFFECT OF BRAZING ALLOYS ON MECHANICAL AND TRIBOLOGICAL BEHAVIOR OF NI-MO SINTERED STEEL

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G.M. Abdo, M.T. Sallam, N.A. Gadallah, and M.I. Negm

### ABSTRACT

The effect of three brazing materials on the mechanical and tribological characteristics of 0.8% C - 4% Ni - 0.5% Mo sintered steel was investigated. Different percentages of copper, cobalt base, and nickel base master alloys were blended with the other alloying powders of this steel. Compaction was done in a uniaxial floating dies under a compaction pressure of 600 MPa. Sintering was then carried out in a continuous vacuum atmosphere at 1150 °C for one hour.

In the as sintered state the addition of 3.5% copper provides the highest strength and hardness while the addition of 5 % cobalt base master alloy offers the highest ductility and toughness. Stress strain diagrams of this steel show two distinct strain hardening coefficients compared with that obtained for the same steel without any brazing addition. This was attributed to the formation of brazing film on the surface of granules of different coefficient of strain hardening. Moreover, the addition of cobalt base and nickel base master alloys results in a pronounced improvement of the wear resistance of such steel. The application of a quenching and tempering heat treatment cycle proved to offer the steel with 5 % cobalt base master brazing alloy distinguished elevated mechanical characteristics and wear resistance.

### INTRODUCTION

Powder metallurgy (PM) is a production process capable of producing finished parts from powders. PM techniques are most applicable when dimensional control is critical [1-2]. Economics favors PM over other methods because of efficient material usage, reduced machining costs and accurate production tolerances.

The alloying elements have a pronounced effect on both mechanical and tribological characteristics of sintered steels [3]. The effect of nickel content, has been studied and it was found that

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\*\*\* Ph.D. Student, \*\* Associate Prof., \* Prof., Dpt. of Mech. Eng., Military Technical College, Cairo, Egypt. + Prof., Dpt. of Mech. Eng., Faculty of Eng., Al-Azhar University, Cairo, Egypt.

the sintered steel containing 0.8% C-4% Ni-0.5% Mo possesses distinct elevated mechanical properties and lower wear rate [4].

Sintering in the presence of a liquid phase has been used for about 40 years in the field of hard metals, cemented carbides, and heavy alloys. To date about 70 % by weight and 90 % by volume of sintered metallic products are manufactured in the presence of a liquid phase [5]. The presence of liquid phase during sintering enhances the inter\_diffusion processes and the material transfer on the surface of granules. This results in rapid densification and high bonding strength among powder particles [6].

The effectiveness of the presence of liquid phase during sintering is mainly controlled by the nature and limits of solubility between the liquid phase and the solid particles, also the degree of wettability of solid phase by the liquid one, the amount of brazing material, the particle size of solid phase, and the sintering temperature [7]. The new trend is the addition of super master alloy as brazing material to substitute the traditional copper addition and to provide liquid phase during sintering [8]. Such master alloys will result in better mechanical and bonding properties in addition to their inherent high properties and their rather wide solidification interval [9].

The impact of the sintering in the presence of liquid phase is specially manifested in the domain of powder products subjected to excessive wear. In fact, in the products sintered in the absence of liquid phase, the wear debris in their majority are whole particles separated from the surface which leads to high wear rates. On the other hand, in the powder products obtained by sintering in the presence of liquid phase, the high bonding strength among particles yields wear characteristics very near to those of conventional material where the wear occurs by either the delimitation, oxidation, or metallic wear mechanism [10].

PM parts produced by incorporated brazing master alloys with other alloying constituents are now flying in General Electric Company engines such as the T-700, F-404, CFM-56, and the F-100. The latter is a developmental military engine [11]. It also provides improved properties which secure high efficient engine operation at higher temperature and open up the way for higher rotational speed of engine components which, in turn, provides improved performance at lower fuel consumption rates [12]. Previous studies on sintered steels with copper addition [13-14], proved a pronounced decrease of wear rate with increasing the sliding speed up to a critical value where this effect is reversed.

The objective of this work is to investigate the effect of different brazing materials on mechanical and tribological properties of Ni-Mo vacuum sintered steels and to determine the influence of heat treatment on their properties.

EXPERIMENTAL WORK

A Manasman iron powder WPL200 with an average particle size 100µm was used as a base powder. This powder was obtained by atomization. The morphology of this powder was found to be mostly spherical. Fine Baudier Ni powder with an average particle size of 4-7 µm was used as the main alloying addition, a constant composition of 4% Ni was adopted in all cases. Also molybdenum powder supplied and produced by Baudier Corporation was used with a fixed percentage of 0.5%. Fine graphite powder supplied by Hoeganaes, of average particle size of 2 µm, was used in all alloys. A 2% graphite, initially added to iron powder, proved to secure about 0.8% C recovery after sintering in continuous vacuum atmosphere.

On the other hand, three brazing alloys were added with various percentage up to 5 %. The first is electrolytic pure copper powder with an average particle size of 20 µm, while the second and the third are cobalt base and nickel base master alloys (SF1, SF40 respectively) produced by Deforo Stellite Powders. The chemical and physical properties of the used brazing alloys are shown in table 1.

Table 1 : Physical and chemical properties of the used brazing alloys.

Type of Powder	Composition (wt. %)								Melting Range °C
	Fe	Cr	Si	B	C	W	Co	Ni	
SF1	0	19	8	0.8	0.4	4	Bal.	17	1010-1050
SF40	3.5	11	3.4	2.2	0.5	0	0	Bal.	970-1150

To secure homogeneous mixing of alloying elements, powders were mixed in a double cone mixer with a speed of rotation of 40 rpm for 1 hr [15]. Compaction was carried out using a uniaxial hydraulic press in a floating dies of both cylindrical and flat shaped cavities to produce wear specimens of 17.3 mm diameter and standard flat tensile specimens as shown in Figs.1 & 2. A compaction pressure of 600 MPa for all specimens was adopted, while sintering was carried out under continuous vacuum atmosphere at 1150°C for one hour. Specimens were tested after sintering either in the as sintered state or after consecutive heat treatment (austenitizing at 850°C for 30 minutes followed by quenching in oil then tempering, at 250 C for one hr is followed). Dimensional changes in axial direction were evaluated for the different compositions.

The wear tests were carried out on a pure sliding disc machine type Timken. The standard test rings are made from hard chromium plated steel of 62 HRC hardness and the test blocks are the

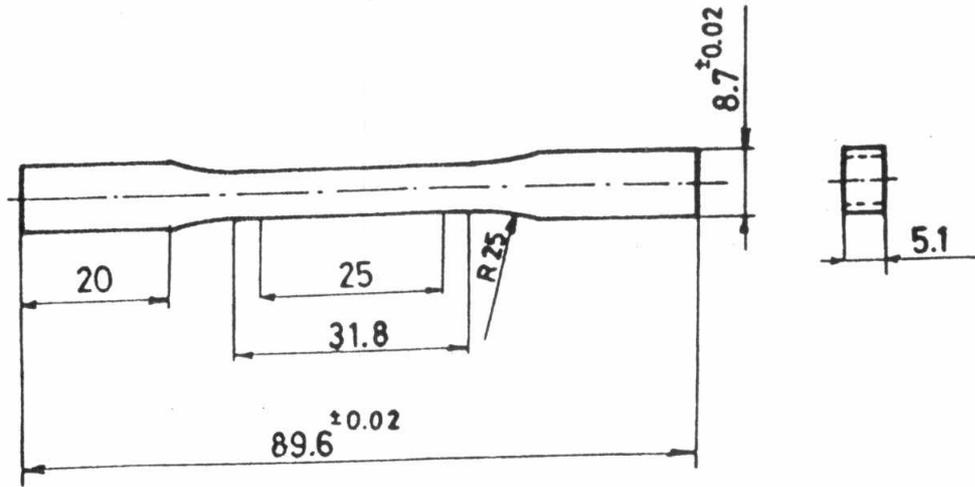
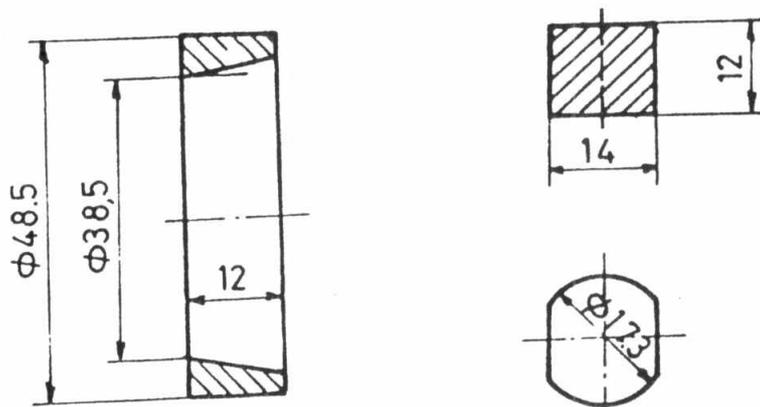


Fig. 1 Shape and dimensions of used sintered tensile specimen.



Test cup

Test block

Fig. 2 Shape and dimensions of wear specimen.

sintered samples. The wear tests were carried out for dry contacts at a speed of rotation of 2 m/sec and at a load of 140 N for constant time of 15 minutes. The volume removed was calculated by measuring the length and width of the resulting scar on the wear surface. The weight loss was then calculated from the value of specific weight determined for the sintered samples. Brinell hardness was measured at different locations on the cross section of specimens, while the tensile properties were determined by the use of a universal tensile testing machine type Instron, of maximum dynamic loading capacity of 100 KN, connected with autographic recorder to plot the stress strain diagram, at a strain rate of  $0.001 \text{ sec}^{-1}$ , a triplicate tests were made for each specimen.

### RESULTS AND DISCUSSION

Figures 3 & 4 illustrate the effect of the different brazing contents on both hardness and ultimate tensile strength of 0.8%C-4% Ni- 0.5% Mo sintered steel. The addition of the cobalt base master alloy (SF1) results in a progressive monotonic increase in both properties. A content of 5% of this master alloy leads to about 20% increase in ultimate tensile strength and hardness. The nickel base master brazing alloy (SF40) has much higher effect on mechanical properties when it is added with percentages up to 2%. For higher contents both strength and hardness are slightly decreased. The addition of copper as a traditional liquid phase forming element, during sintering, and which is commonly used in powder products showed the highest peak values of strength and hardness at about 3.5% Cu. Further increase in copper content leads to a pronounced drop in the mechanical properties.

At the adopted sintering temperature  $1150^{\circ}\text{C}$ , which is higher than the melting temperature of copper and the melting ranges of both master brazing alloys, some fraction of the solid powder particles are in position similar to that of suspension in the liquid and slide over one another by capillarity, thus producing a particle rearrangement, and consequently densification is rapid and reaches a high level. On the other hand, the components of solid particles can dissolve into the liquid, the intersolubility at the contact points is higher than elsewhere in the solid due to the dependence of activity on the stress field. Consequently, a transfer of material via the liquid phase occurs between the contact areas and the rest of powder, which leads to further densification. During this stage the particles begin to bond together by forming necks[6]. The final stage is characterized by the disappearance of the liquid phase and the coalescence of the solid particles lead to densification through solid diffusion phenomena. This has, in its turn, an impact on improving the mechanical strength and hardness of sintered compacts.

The microscopic examination of the sintered steel with nickel base master brazing addition Fig. 5, shows the formation of skeleton from the brazing material along the surface of

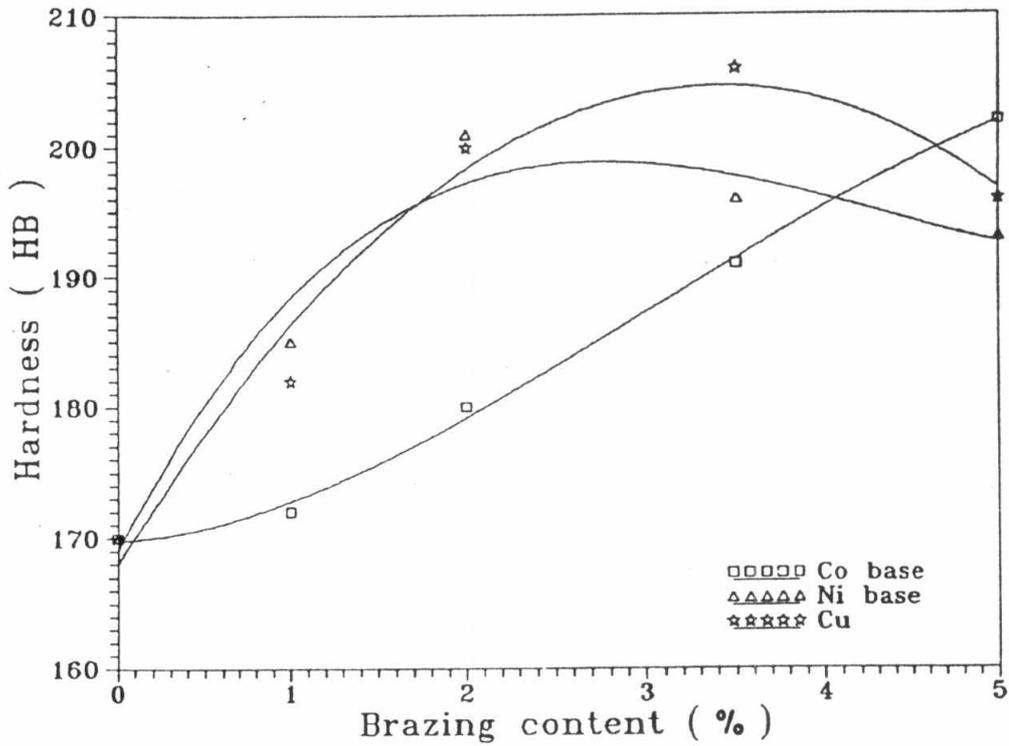


Fig. 3 Effect of brazing alloys on hardness of Ni-Mo sintered steel

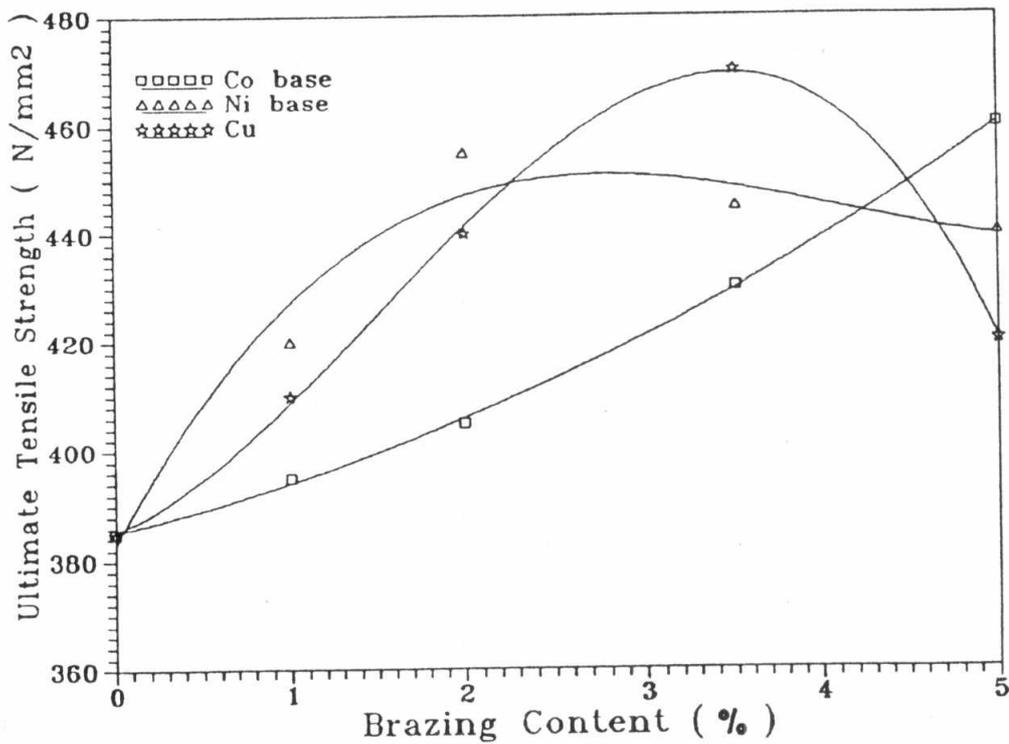


Fig. 4 Effect of brazing alloys on UTS of Ni-Mo sintered steel

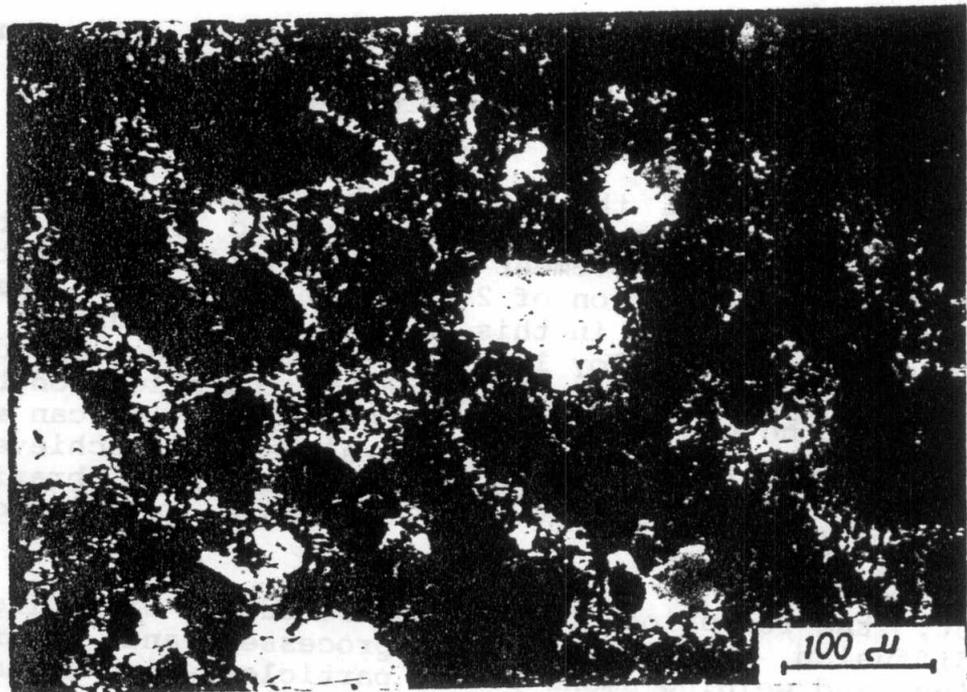


Fig. 5 Micro-structure of sintered steel containing (0.8% C- 4% Ni- 0.5% Mo).

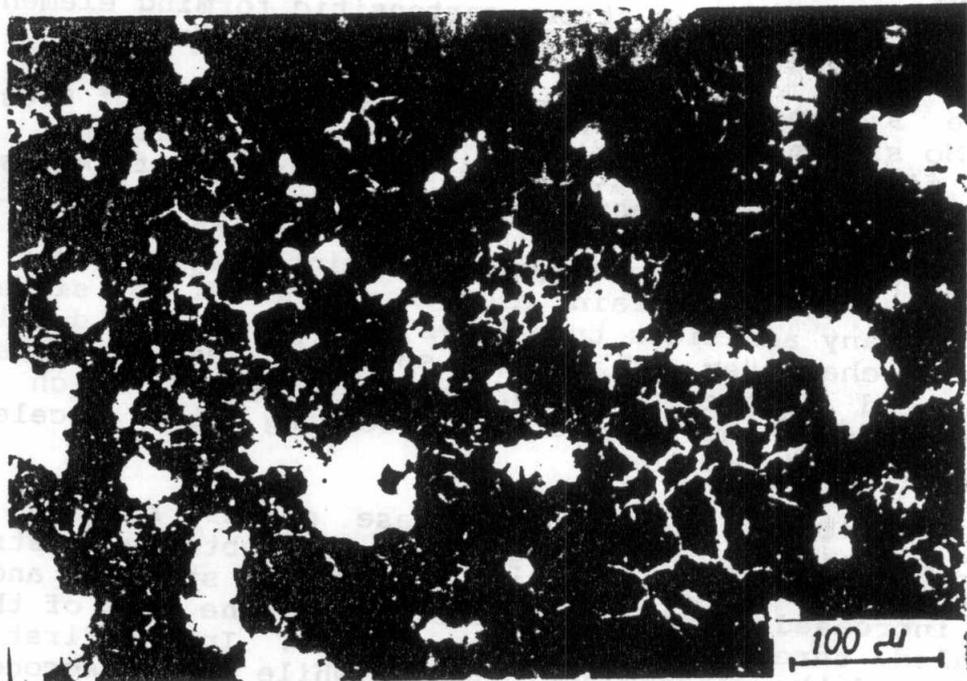


Fig. 6 Micro-structure of sintered steel containing (0.8% C- 4% Ni- 0.5% Mo -3.5% Ni base master brazing alloy).

particles, which increases the contact areas and consequently improves the bonding strength among particles compared with the structure of the same steel obtained without brazing addition shown in Fig. 6.

Figure 7 illustrates the effect of brazing content on ductility of Ni-Mo sintered steel in the as sintered state. It can be reported that an improvement of about 20 % in ductility can be obtained by the addition of 2 % copper or cobalt base master alloy. Further increase in this content or the addition of nickel base master brazing alloy lead to slight decrease in ductility. Figure 8 shows the effect of different brazing alloys on the impact resistance of notched specimens of this steel. We can state that a remarkable increase of impact resistance is achieved by the addition of about 3.5% copper or nickel base brazing alloy. While the cobalt base master alloy offered a net improvement of 50% at a content of 5%.

In fact, the formation of liquid phase during sintering enhances the diffusion and homogenization processes and insure better bridging and welding among powder particles which strengthen the inter-granular path which is the dominant fracture route in powder products. This has, in its turn, a pronounced effect in improving ductility and impact resistance. The lower values obtained for these properties in case of nickel base master brazing alloy compared with that of cobalt one can be attributed to the constitution of the nickel base brazing alloy and the effect of nickel as a strong martensitic forming element leading to cementing phase relatively of brittle character.

Figure 9 illustrates the stress-strain diagram of 0.8% C-4% Ni-0.5% Mo sintered steel without any brazing additions, and in the same figure are also displayed the behaviors of this steel when 3.5% by weight of either cobalt base, nickel base master brazing alloy, or pure copper were mixed together with the basic constituents before compaction and sintering. It can be stated that the stress strain diagram of the Ni-Mo sintered steel without any additions translates, with its low ductility, the brittle character of powder specimens usually observed and attributed to the porous nature of such steels which represents incorporated initial cracks serving to accelerate the inter-granular fracture.

The addition of 3.5% cobalt base master brazing alloy has provoked significant changes in the obtained stress-strain diagram. Both values of ultimate tensile strength and ductility were increased, and on the other hand, the form of the diagram revealed three distinct stress domains. In the first domain manifested the elastoplastic strain, while in the second and third domains two plastic strains characterized by different hardening coefficients were manifested. This behavior can be explained by the different nature of the deformation mechanisms in the low and high stress levels. In the second domain with relatively low stress level the plastic deformation takes place in its majority in the base granules which tend to deform and elongate in this

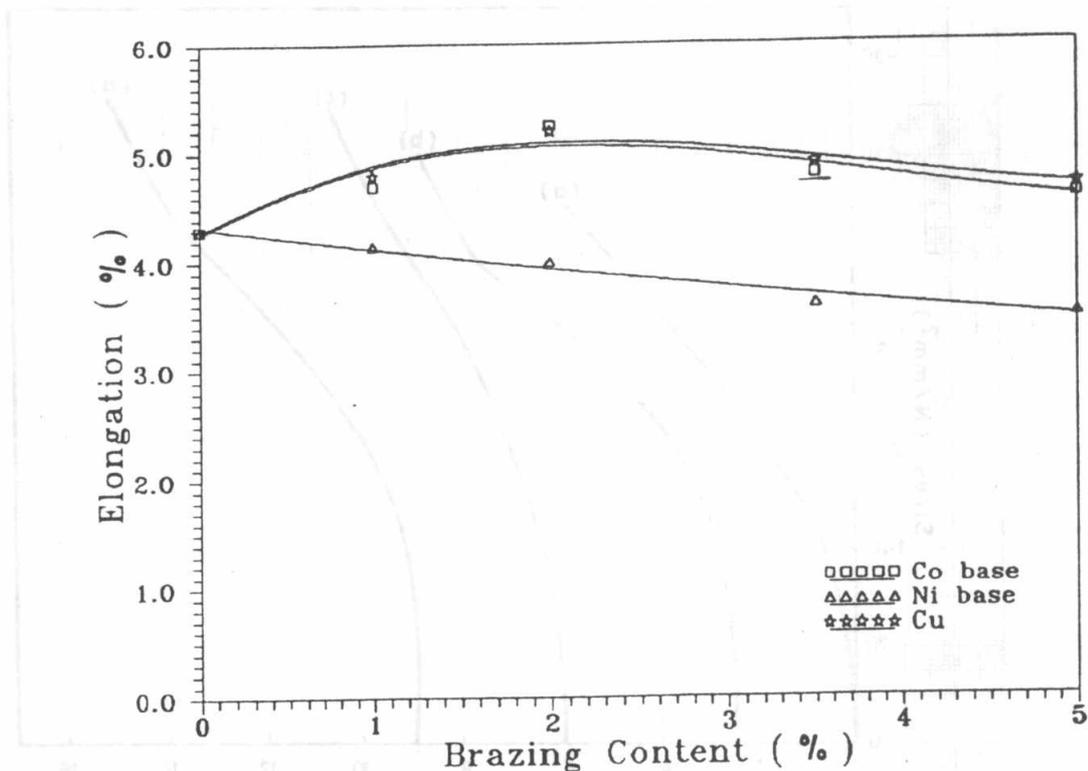


Fig. 7 Effect of brazing alloys on ductility of Ni-Mo sintered steel

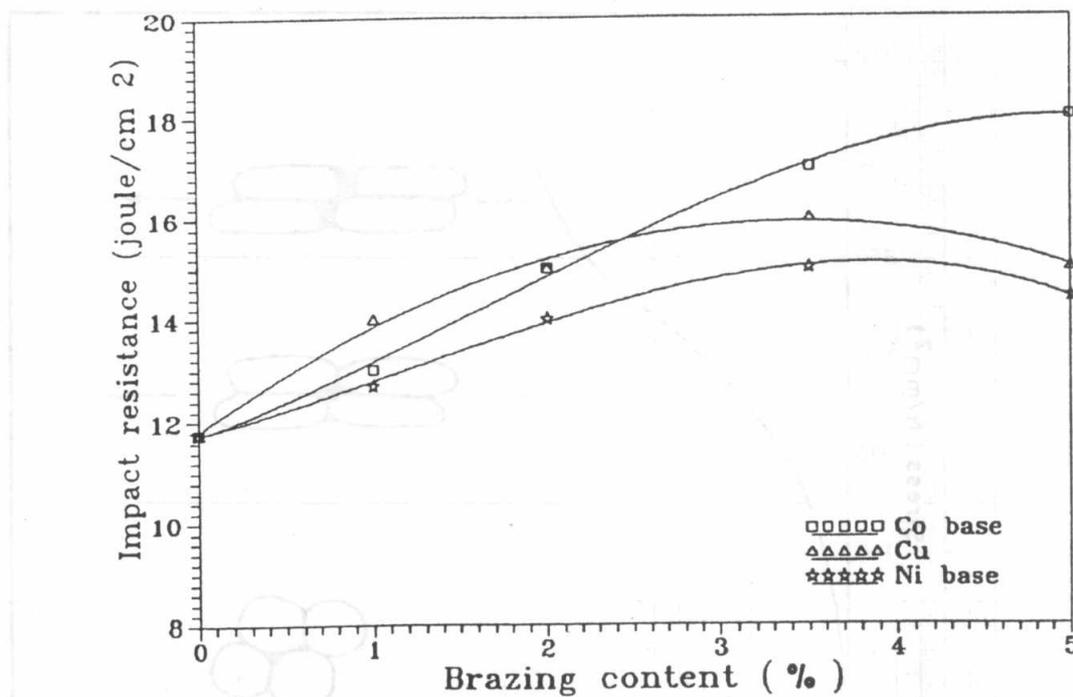


Fig. 8 Effect of brazing alloys on impact resistance of Ni-Mo sintered steel

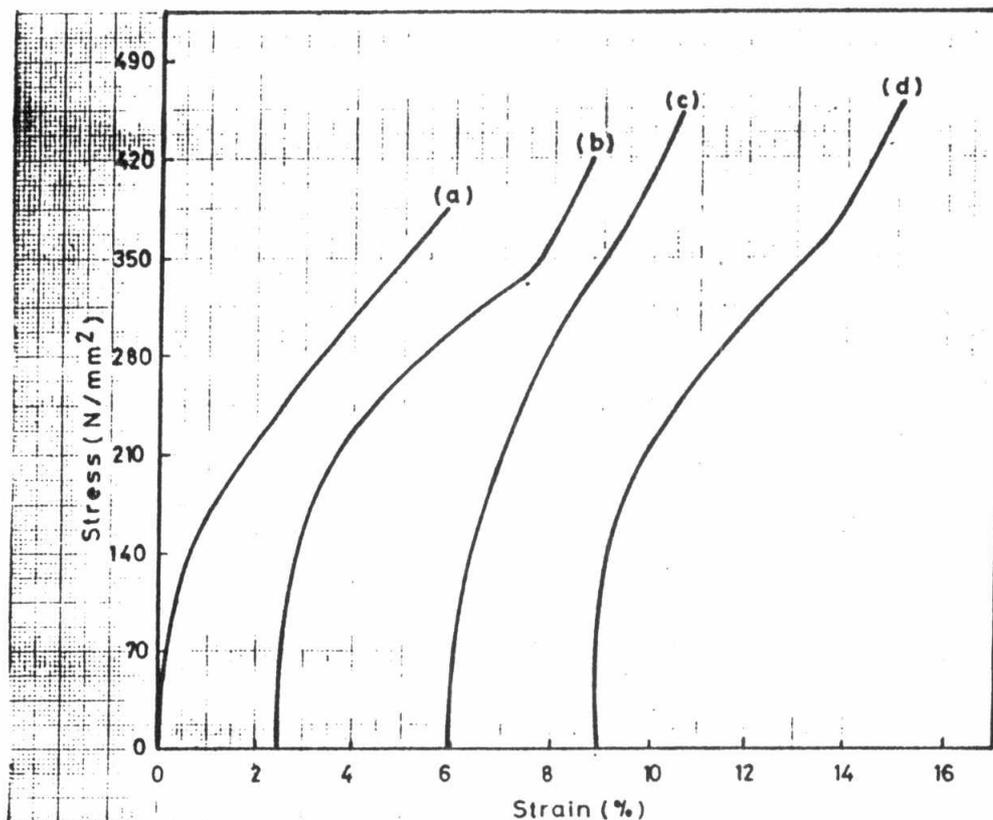


Fig. 9 Stress-strain diagrams of Ni-Mo sintered steel containing  
 (a) 0 % brazing material. (b) 3.5% Co base master alloy.  
 (c) 3.5% Ni base master alloy. (d) 3.5% Cu.

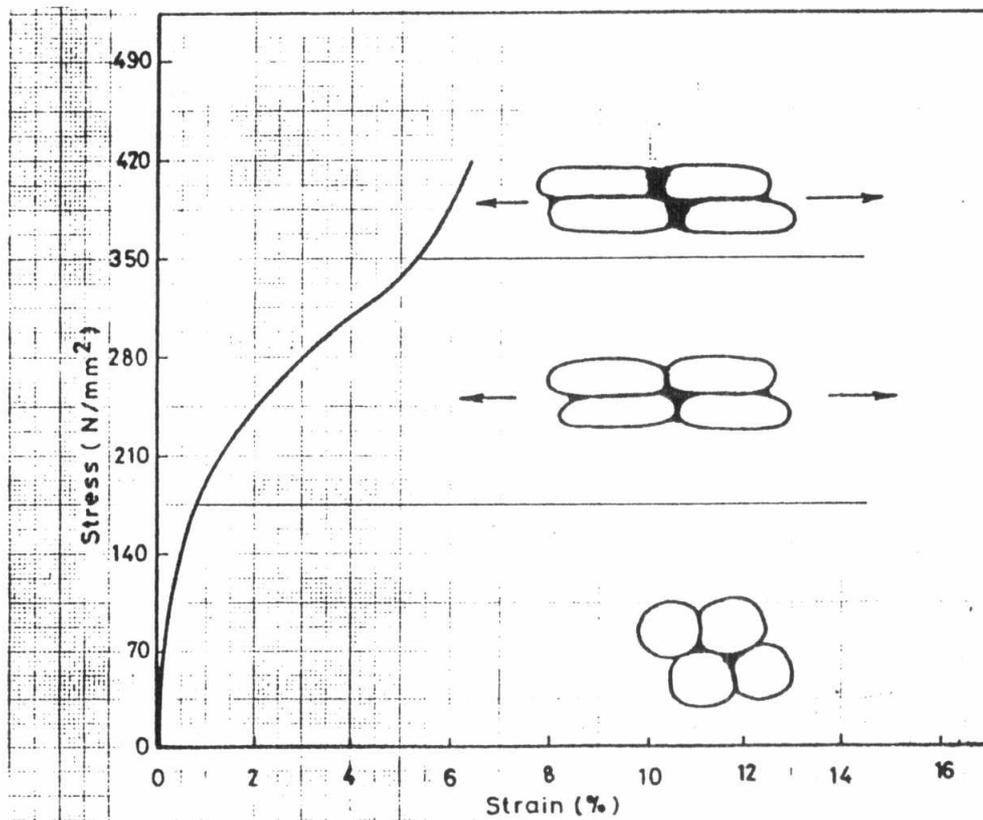


Fig. 10 Effect of stress level on deformation modes of sintered steel containing 3.5% Co base master alloy.

domain as shown in Fig. 10. The structure of this base granules is BCC characterized by numerous slip systems and low coefficient of strain hardening. With increasing the stress level the plastic deformation will be induced in its majority in the brazing alloy and hence the high strain hardening coefficient, observed in the third domain, can be attributed to the nature of the HCP structure of this cobalt base brazing skeleton formed on the surface of granules.

Moreover, the stress-strain diagram obtained on the Ni-Mo sintered steel with 3.5% nickel base master brazing alloy Fig. 9, showed also the three stress domains. It can be noted that the obtained plastic strain in the second stress domain is much lower than that obtained in the case of the sintered steel with cobalt base brazing addition and consequently the total deformation is also lower. This can also be explained by the fact that during the liquid phase sintering, the liquid phase diffuses into the solid one and forms a series of solid phases. In the case of nickel, a martensitic structure is promoted upon cooling which deeply influence the deformation of granules in the second domain. The stress-strain diagram of Ni-Mo steel containing 3.5% Cu showed very similar behavior to that of the same steel with cobalt base master alloy addition, but it results in a slightly higher strength values.

The effect of the three brazing materials on dimensional changes of this sintered steel is shown in Fig. 11. All these brazing materials reduce the total shrinkage of specimens and produce a swelling effect. This has often been attributed to the diffusion of brazing material into the base iron particles leaving its initial sites as large stable pores [16]. More recently, however, it has been shown [17] that the expansion observed in these compacts is due to the penetration of the molten brazing phase into the spaces between the base iron particles and some of the grain boundaries inside the particles. The measured swelling effect due to the addition of copper was much higher than that obtained in the case of the two other master brazing alloys. This swelling effect by the addition of 3.5% Cu completely compensates the shrinkage of compacts and results in a zero total dimensional change. Further addition of copper results in a positive change. In fact, pure copper has a fixed melting point at which all the content of copper changes to the liquid phase and consequently the available amount of liquid copper at that moment results in a significant penetration and separation of the iron particles by the copper rich phase. In the case of the cobalt base and nickel base master brazing alloys the sluggish melting range allows only a limited content of liquid phase to be present at a time. This liquid phase may diffuse and disappear immediately and consequently the separation of iron particles is less significant.

The effect of addition of master brazing alloys on wear rate of this steel is shown in Fig. 12 together with the effect of copper as a traditional brazing material in powder products. It can be noted that all the brazing materials have a remarkable effect in reducing the wear rate. A composition containing 3.5% of any of

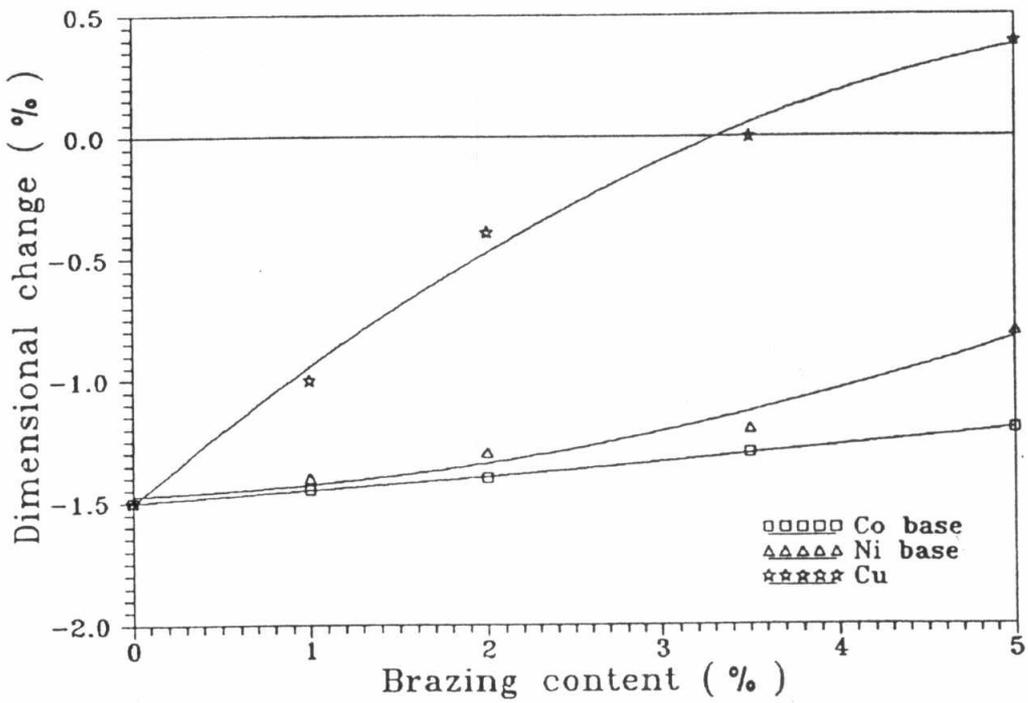


Fig. 11 Effect of brazing alloys on dimensional change of Ni-Mo sintered steel

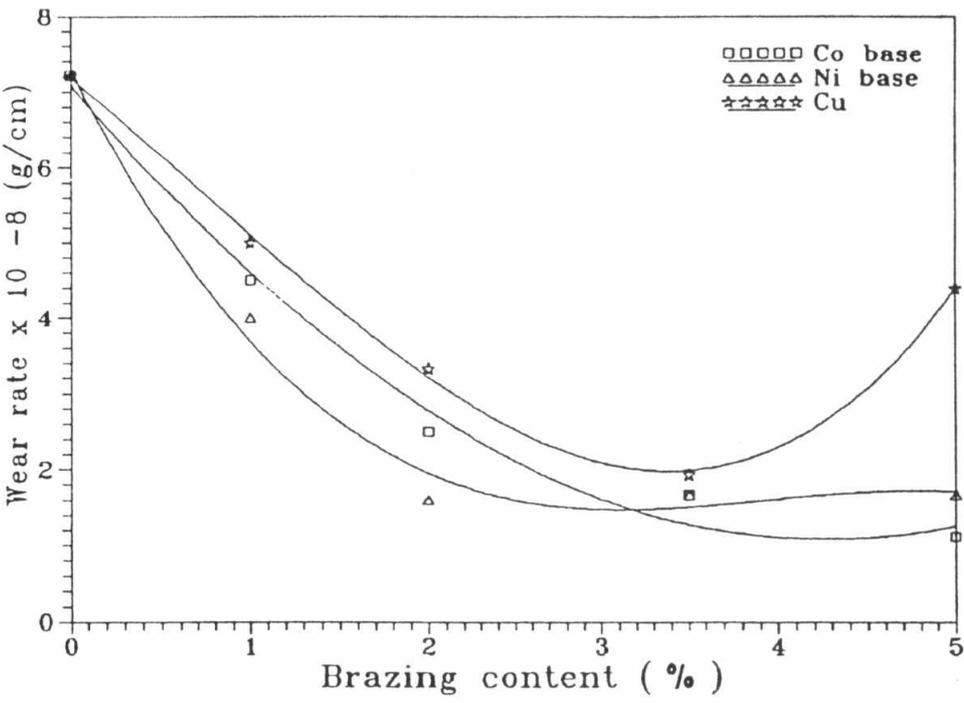


Fig. 12 Effect of brazing alloys on wear rate of Ni-Mo sintered steel

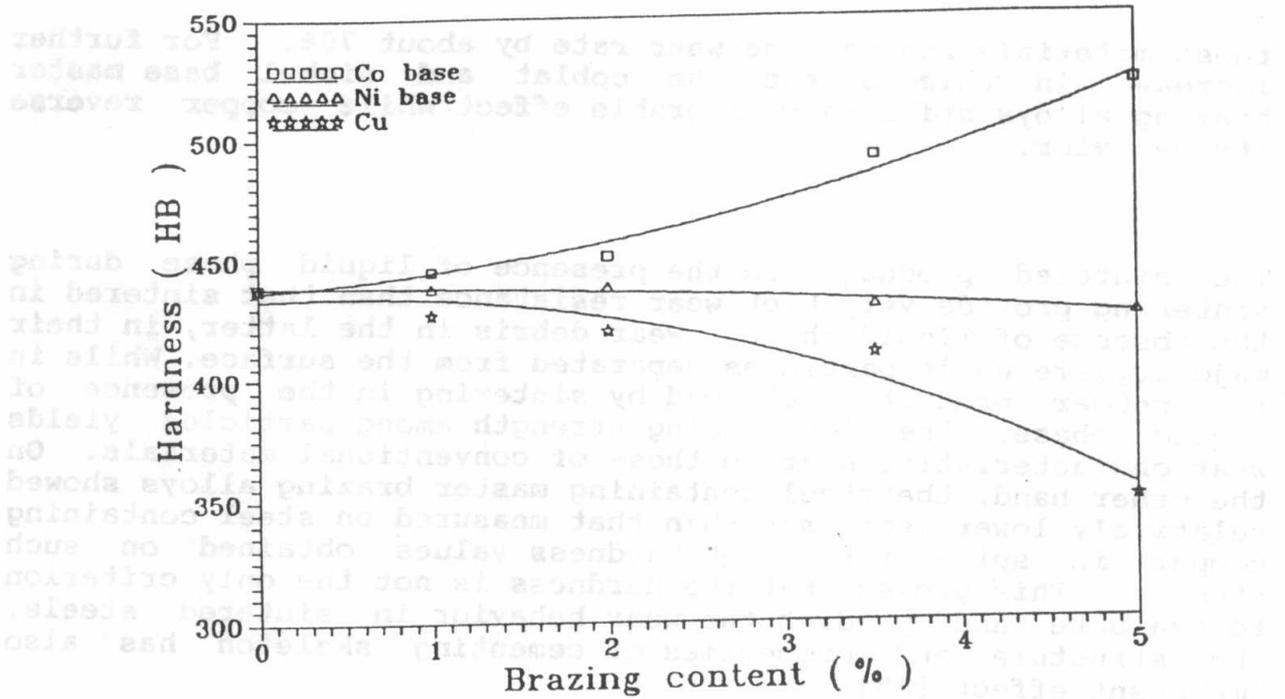


Fig.13 Effect of brazing alloys on hardness of heat treated Ni-Mo sintered steel

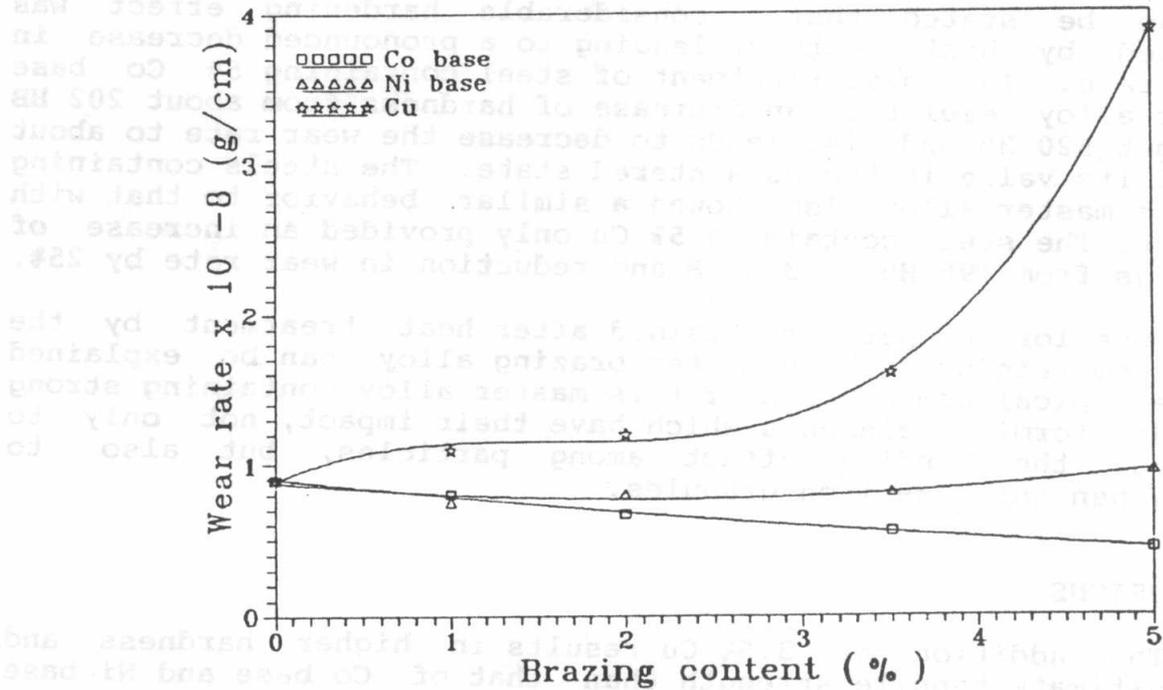


Fig. 14 Effect of brazing alloys on wear rate of heat treated Ni-Mo sintered steel

these materials reduces the wear rate by about 70%. For further increase in this content the cobalt and nickel base master brazing alloys still show favorable effect while copper reverse its behavior.

The sintered products in the presence of liquid phase during sintering provide very high wear resistance than that sintered in the absence of liquid phase. Wear debris in the latter, in their majority, are whole particles separated from the surface. While in the powder products obtained by sintering in the presence of liquid phase, the high bonding strength among particles yields wear characteristics near to those of conventional materials. On the other hand, the steel containing master brazing alloys showed relatively lower wear rate than that measured on steel containing copper in spite of the high hardness values obtained on such steel. This proves that the hardness is not the only criterion to evaluate and predict the wear behavior in sintered steels. The structure and properties of cementing skeleton has also important effect [18].

Steels of different brazing alloys were heat treated by austenitization at 850°C followed by oil quenching and tempering at 250°C for 1 hr. The effect of these subsequent treatments on the hardness and wear resistance of sintered steel containing Cu, Ni base, and Co base master brazing alloys are shown in Figs. 13 & 14. It can be stated that a considerable hardening effect was obtained by heat treatment leading to a pronounced decrease in wear rate. The heat treatment of steel containing 5% Co base master alloy results in an increase of hardness from about 202 HB to about 520 HB and also leads to decrease the wear rate to about 50% of its value in the as sintered state. The steels containing Ni base master alloy also showed a similar behavior to that with Co base. The steel containing 5% Cu only provided an increase of hardness from 196 HB to 345 HB and reduction in wear rate by 25%.

The superior properties obtained after heat treatment by the steel containing Co base master brazing alloy can be explained by the typical composition of this master alloy containing strong carbide forming elements which have their impact, not only to improve the binding effect among particles, but also to strengthen the base iron granules.

#### CONCLUSIONS

1. The addition of 3.5% Cu results in higher hardness and ultimate tensile strength than that of Co base and Ni base master brazing alloys, and secures zero dimensional change.
2. The steel containing master brazing alloys showed relatively higher wear resistance than that measured on steel containing copper in spite of the high hardness values obtained on

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such steel. This proves that the hardness is not the only criterion to evaluate and predict the wear behavior in sintered steels. The structure and properties of cementing skeleton has also important effect.

3. The stress-strain diagrams of these steels sintered in the presence of liquid phase show two distinct strain hardening coefficients as a result of the formation of brazing film on the surface of granules having different structure.
4. A considerable hardening effect can be obtained after quenching and tempering of sintered steels with brazing alloys. An increase in hardness from about 202 HB after sintering to about 520 HB after heat treatment was obtained in the steel (0.8% C-4% Ni-0.5% Mo-5% Co base master alloy). Moreover, this steel possesses higher wear resistance over that measured on steels with copper or nickel base master brazing alloy after heat treatment.

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