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A Study on Wear Resistance, Hardness and Impact Behaviour of Carburized Fe-Based Powder Metallurgy Parts for Automotive Applications

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ABSTRACT

In order to study the mechanical and triboloical properties of powder metallurgy (PM) parts under different process parameters, the specimens were used in pack carburizing processes. These specimens made from industrial test pieces were carburized in a powder pack for about two to five hours at a temperature of about 850˚C - 950˚C. The effects of austenitization and quenching are investigated on some specimens. Also the wear tests are performed by means of a pin-on-disc tribotester using roll bearing steel as the counterface material. The results indicate that by appropriate selection of process parameters, it is possible to obtain high wear resistance along with moderate toughness. It is concluded that surface treatments increases the wear resistance and performance of PM parts in service conditions. By increasing the role of PM in industry which resulted from their ability to produce the complex shapes, high production rate, and dimension accuracy of final products, they need to be heat treated. Carburizing method was selected as a surface hardening method for PM parts. Results of wear and hardness show considerable enhancement in mechanical properties of PM parts.

Keywords: Carburizing; Wear Resistance; Powder Metallurgy

1. Introduction

Nowadays powder metallurgy method has been noticed because of its outstanding advantages such as cost effective and ability to produce complex parts. Powder metallurgy is a method which produces the parts by compacting the metal powder and then sintering in order to increase the strength. Since powder metallurgy deals with metal powders, this process has wide choice for material composition which might be not possible to produce by other methods [1,2].

Powder metallurgy is able to decrease the mechanical processing stages. Jang *et al.* [3] have compared stages involved the forging method and powder metallurgy in production of automobile parts. They have shown that powder metallurgy method has considerable lower steps compare to forging process.

The increasing demands of powder metallurgy parts in industry need to enhance the mechanical properties such as hardness and wear resistance by surface hardening processes such as bronzing, nitriding or carburizing. It should be noted that the porosities resulted from the connection of the pores are inevitable in powdery parts which affect the density, thermal conductivity, electrical resistance and diffusibility (of liquids and gases) [4]. Not only do porosities decrease the hardness of steel, but also they can decrease the thermal conductivity because of the porosities' refractory properties. Consequently they decrease the steel's hardenability. The open pores let the carburizing and nitrating gas diffuse at the depth. The penetration of carbon in steel causes the embitterment and sometimes distortion of the whole part (**Figure 1**) while it is expected to have hard surface, tough center, and wear resistant after carburizing [5].

Jang *et al.* [3] have used the plasma nitriding process for increasing the hardness and wear resistance. They enhanced the surface hardness even more than forging parts with the same chemical composition. Also they found out that Ni content plays an important role in samples' toughness. Moreover, according to their observations a toughness of powder metallurgy parts was as great as forged metals.

J. Cerogivev *et al.* [1] increased the hardness and wear resistance by C_7H_7 gas. They observed enhancement in wear resistance by pin on disc machine. As it was mentioned earlier control of penetrate gas into the surface is not easy in presence of porosities. Moreover, equipment

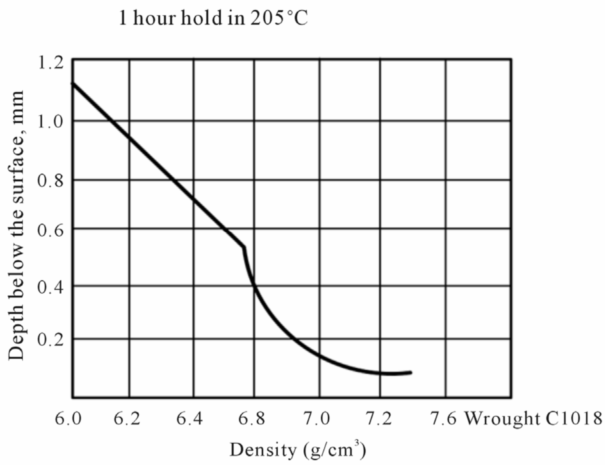

Figure 1. Depth of diffused carbon vs. density.

and accessories for gas carburizing increase the cost of the process.

Duzcuoglo *et al.* [6] investigated the borided, carbourized and borocarrburized effect on AISI 8620 steel. They observed lamination and tearing between hard surface and core was minimal when carburizing method was applied. Moreover, contact fatigue mechanism was main fatigue mechanism in boronized and carbo-boronized methods. The wear profile at the interface of the hard surface and core was lowest in carburized samples compared to other two methods.

Senatorski *et al.* [7] conducted two different wear tests on carburized and nitrated layers on different types of steel. Although detailed comparison is too hard because the steel samples and surface hardening treatments were not identical, generally carburized samples show deeper hardened layer compared to the nitrated samples. It is worth noting that carburizing treatment is a controllable case hardening process whereas nitriding process was practiced without adequate control. Therefore, depth of hard layer in nitriding process would be based on experience or guess work.

Ozbek *et al.* [8] measured the wear resistance of AISI 8620 treated by pulse plasma technique. They have noticed that pulse plasma technique by own cannot enhance the wear property of the substrate surface. However by conducting the carburizing process for 2 hours and then sing the pulse plasma technique, wear resistant of the substrate would be enhanced. Therefore, the main idea for surface modification is carburizing process.

It can be seen that carburizing method is a capable process to change the surface composition in order to increase the hardness and wear resistance. Although boronizing, nitration and other similar method are pointed out in literature, carburizing method still has advantages over other similar methods such as cost effective and controllability of hardened layer. Moreover, in identical condition, carburizing method can create a thicker layer at the top of the substrate compare to the other case hardening methods. This can be because of higher diffusion rate of the C in substrate.

R. M. Munoz *et al.* [9] have used the ion nitriding process which is applied for samples with different V contents. The surface's hardness has been increased because of formation of Fe_4N and VN. They concluded that V content affect the thickness of ion-nitride layers.

In this paper, solid carburizing method has been used to increase the wear resistance. Solid carburizing method is a very cost effective process compare to ion-nitride, bronzing and gas carburizing in terms of required equipments. Moreover, in this research alloying elements in order to form carbides have not been used. Effect of carburizing time on wear resistance and impact toughness was investigated. Finally the optimized condition was introduced.

Mentioned reasons and increasing the usage of powder metallurgy parts in industry, stimulated author to use carburizing method as a surface hardening method for powder metallurgy. In this research, feasibility of carburizing treatment on powder metallurgy parts was studied.

2. Materials and Research Process

To prepare the test samples, 64 round discs with 7 mm diameter and 10 mm thickness that are made of low carbon alloy and produced by powder metallurgy method, were considered. The discs' chemical compositions are shown in **Table 1**.

Before heat treating the samples, first eight samples were placed in a powder containing 87% of coke, 10% of NaOH and 3% of Na_2CO_3. Second eight samples were placed in cast iron powder so as to protect surfaces from oxidation during process. In each group we intend to prepare six samples for impact test, metallography and wear test. Since the results of the experiment when placing the samples in a furnace with the temperature of about 850˚C, which is the same temperature as the carburizing circle in powder metallurgy factories, didn't

Table 1. Chemical composition of powder parts.

% C (max)	% Si (max)	% Mn (max)	% S (max)	% P (max)	% Fe (max)
0.02	0.05	0.15	0.015	0.015	Remain

come out outstandingly satisfactory, therefore, the samples were placed in a furnace with the temperature of about 950˚C according to Fe-C equilibrium diagram for low carbon steel.

Each group of samples contains eight samples for carburizing eight samples for austenitization in different holding time two, three, four, and five hours to compare the results. During the heat treatment the samples in the carburizing powder are carburized and the samples in the cast iron powder are austenited in all repeatations of the experiment. Finally, the samples which are kept in the furnace for different mentioned times, were quenched in oil.

Charpy tests are applied on standard impact test samples (without notch) at the room temperature. A "pin on disc" machine with pins made of hard steel (AISI 52100) is applied on wear test samples and lastly the macro and micro hardness tests are applied on metallography samples.

3. Results and Discussion

3.1. Mechanical Properties and Microstructure

The impact and hardness test results of different heat treatments are shown in **Table 2**.

Regarding the tests applied on raw samples, the hardness of raw material was measured 23 RB. Moreover the average impact test results applied on raw samples, show 15 J absorbed energy. However, after two hours of carburizing and quenching in oil, their hardness increases to 105 RB and the impact test result decreases to 11 J.

By increasing the duration of carburization, we realize a subtle change in the hardness results, however the impact test results decreases down to 3 J. Microstructure studies and micro hardness tests in different zones of the steel's surface show that carbon can diffuse in steel so deeply. Usually having a thinner and denser layer of carbon in the surface provides uniform and larger amount of hardness.

It seems that in carburization process we have two parallel effects which affect impact test results simultaneously. Firstly sintering of metal powder which increases the toughness and hardness of the powder parts and secondly the carbon diffusion which decreases the impact results of the powder parts.

The competition between these two effects has a crucial role in final mechanical properties. Mentioned effects depend on parameters like steel's chemical composition, porosity percentage, carburizing potential and the process temperature. For powder parts with a certain composition, we can optimize the parameters which control the impact test results.

Carburization process is known to be a process which is used for achieving a higher fatigue strength and wear resistance for thick-sectioned steels in industries. In order to optimize the dynamic properties of the steel part, the amount of the steel's carbon content must be adjusted with the porosity percentage of the part.

The solid carburization process used in this research is much more preferable to gas carburization process for the powder parts with more than 15% porosity. Gas carburization process is usually applied at the temperature of about 900˚C - 930˚C. In order to prevent a deeply carbon diffusion in the parts, this process lasts for only a short while. It must considered that the carbon potential of the furnace for powder parts heat treatments must be higher than the carbon potential of the furnace for the usual heat treatments of steels with similar chemical composition.

For more clarification of the effects of carburization on impact test result, some other samples were placed in cast iron powder so as to have their surfaces protected and then heat treated them at the same temperature (950˚C) during the same time and then quenched them in oil. As it is shown in **Table 2**, the hardness results were 65RB and the impact test result was 21 J. The increase in the impact data shows when having no surface treatment, demonstrate the changes resulted from the connection of the powder parts. Micro structural studies while austeniting process, the sintering process is happen more completely and that is the reason why the impact test results increase. Yet it must be considered that a higher density of sample tests affects the powder parts properties.

Table 2. Impact energy and hardness results.

Sample/Heat Treatment	Hardness (RB)	Impact Test (J)
Raw Material	23	15
2 Hours in 950˚C Austenite and Oil Quenched	65	21
2 Hours in 950˚C Carburized and Quenched in Oil	105	11
3 Hours in 950˚C Carburized and Quenched in Oil	98	6
4 Hours in 950˚C Carburized and Quenched in Oil	101	4
5 Hours in 950˚C Carburized and Quenched in Oil	104	3

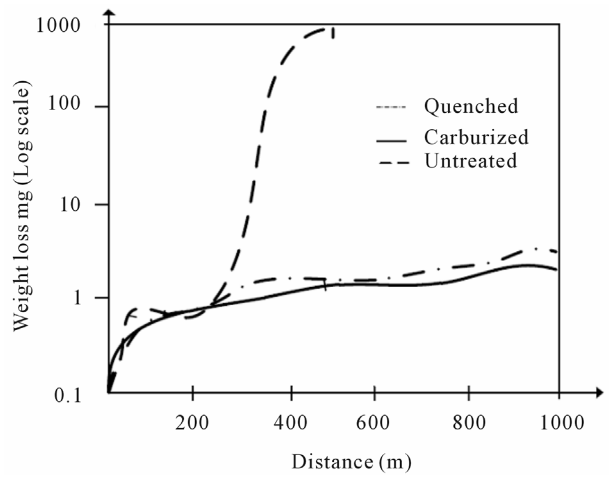

Figure 2. Wear resistance vs. distance in difference samples.

3.2. Wear Resistance

A summery of wear test (pin on disc) results is shown in **Figure 2**. These results are based on the weight loss during the distance the pin runs. Different loads were tested to achieve optimum results. In one hand in a low load (a 3 kg load), no negligible weight loss is resulted for carburized samples. On the other hand in a high load the huge weight loss made the evaluation so hard. The optimum load is chosen to be 6 kg for all tests. The samples were worn when running a distance of about a thousand meters. The samples' weight loss produces a wear resistance indication for us.

Figure 2 shows that wear resistance results in a raw sample during the first hundred meters is gradually increased while during the second hundred meters it increases so fast that made the experiment last for only a four hundred more meters. During the second hundred meters the raw sample's wearing caused one gram (1 g) weight loss.

The type of wearing and the weight loss of the raw samples show that the friction parameter has high variable values. For the quenched and carburized samples, the weight loss is very smoothly increased. The weight loss of the samples which are carburized for two hours, is only 5 mg after the 1000 meters of the pin's running

Desired results in charpy test also can be seen in the austenited and quenched samples. This is probably caused by the sintering process happening at 950˚C. The increase of the parts' hardness can be because of oil quenching process.

In spite of low carbon content used in the experiment samples, some scattered particles are observed in microstructure which shows quite high hardness.

4. Conclusion

All in all, test results clarify that carburizing can be a suitable process for surface treatments of powder parts. Because of no uniformity of the surface hardness of powder parts (before heat treatment), hardness tests and micro hardness tests aren't suitable to be applied and reported. Also with the aid of pin-on-disc method, diffused carbon depth can be estimated in parts.

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