DEVELOPMENT OF SINTERED MECHANICAL FUSE PARTS FOR HIGH POWER SWITCHES

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Abstract: It is required a function that the high power switch in case overloaded will be disconnected from the power. The development of a mechanical fuse part having such a function is presented here. This part can be realized by satisfying two functions simultaneously; the part has sufficient fatigue strength to transmit power without breaking, and it breaks promptly to disconnect the power if an overload occurs. This can be realized by developing a material having high fatigue limit. Such material was investigated and was found that a high fatigue limit ratio is achieved by steam treating an Fe-Cu-C material sintered compact with a decreased amount of carbon. This newly developed material has recently been applied to such required mechanical fuse parts.

1. INTRODUCTION

Transmission of electricity is made by high-voltage lines by means of high voltage substations. In these stations cars and medium and high voltage devices meet, such as transformers, switches, disconnectors, cells, measuring apparatus. In higher voltages exceeding 10 kV electrical arcs occur at any maneuver of closing/opening the circuit. Avoid maintaining arc in a time machine to determine the destruction can be achieved by suddenly opening and closing mechanisms of these circuits, including arc extinction.
I therefore started researching the possibility of developing a mechanical fuse part which would disconnect the power by breaking a part of the power transmission part if a load exceeds more than the regulated amount for protecting the apparatus. For such a mechanical fuse part to work precisely, two functions are necessary, one is that it must have sufficient fatigue strength to transmit power without breaking, and the second is that it should break promptly in order to disconnect the power if an overload occurs.
Therefore, a high fatigue limit ratio (fatigue strength/tensile strength) is required [1]. Generally, ferrite obtains a higher fatigue limit ratio than pearlite in a carbon steel, namely the fatigue limit ratio increases as the amount of carbon is decreased [2]. Therefore, in order to find the optimum high fatigue limit ratio, sintered compacts with various amounts of carbon were used and the process of steam treatment was applied to improve the fatigue strength even more by making the spherical pores in an Fe-Cu-C material.

2. EXPERIMENTAL PROCEDURE

The specimens used for experiments were made from sintered steel. Raw materials used were Fe, Cu and graphite powders. The iron powders used in the studied powders mixtures are powders from current production of " S.C.Ductil SA Buzau" and present the following chemical and physical features, Table 1.
The copper powder used (STAS 10283 - 75) is obtained by electrolysis made by Fukuda Metal Foil & Powder Co., Ltd. The chemical composition and the physical features are shown in Table 2.
Graphite was obtained by using mechanical processes at Salrom – Exploatarea Miniera Ramnicu-Valcea, Romania. The increasing of carbon contain is realized mainly by floating, after the sorts are obtained by hydraulical or pneumatical classifying. It was used dried natural graphite type F95, first quality, with the following quality conditions: carbon - min.

95 %; sulfur - max. 1 %; humidity - max. 2%; rest granulation (on mesh - 0,063 μm) - max. 8%.

Table 1. ***The chemical composition and physical features of iron powders***

CHEMICAL COMPOSITION						
TYPE	Chemical elements, [%]					
	C	S	Mn	Si	P	H_2
DP200HD	< 0.01	0.002	0.073	0.017	0.004	0.056

PHYSICAL FEATURES								
TYPE	The size of particle				Flow rate (sec./ 50 g)	Apparent density	Compressibility ρ, [g/cm^3]	
	+ 160 μm	- 160 + 100 μm	- 100 + 63 μm	- 63 μm				
	Granulometric distribution (%)						P=400 MPa	P=600 MPa
DP200HD	3.9	34.7	35.9	25.5	26.86	2.98	6.75	7.1

Table 2. ***The chemical composition and the physical features of copper powders***

CHEMICAL COMPOSITION								
TYPE	Chemical composition, [%]							
	Cu	Fe	Pb	As	Sb	SO_4	O_2	water
CE-15	99.5	0.02	0.05	0.005	0.01	0.01	0.4	1

PHYSICAL FEATURES								
TYPE	The size of particle, [mm]						Flow rate, [sec./50g]	Apparent density, [g/cm^3]
	+0.5	+0.2	-0.2-+0.125	-0.125-+0.09	-0.09-+0.063	-0.063		
	Granulometric distribution, [%]							
CE-15	-	-	max. 3	20±5	20±5	min. 50	25-40	2.5-2.7

In the Fe-Cu-graphite mixtures, iron represents the main amount, and then copper powder is added in order to increase mechanical strength of sintered powder parts. The graphite powder added to iron-copper mixture decreases the parts dilatation during sintering process.
The copper powder in iron-copper mixture influences the dimensional instability of sintered powder part. The dilatation of created sintered powder parts with the copper content reaching a value over 1% for more than 4% copper [3]. The use of graphite in iron-copper mixture permits the dilatation decreasing by iron - copper - carbon eutectic forming, rich in iron, with melting temperature around 1100 °C. The dimensional variation of sintered powder parts made of iron - copper - graphite is minimum for compositions up to 5% copper for 1% graphite.
The best graphite content is between 0.4-1.5%, typical of minimum dimensional instabilities. In order to study some sintered powder parts with high fatigue limit, it was considered the various compositions indicated in Table 3.

Table 3. ***Compositions of specimens, [mass%]***

Specimen No.	Fe	Cu	Graphite	Lubricant (zinc-stearate)
1	97.0	2.5	0.5	0.8
2	96.8	2.5	0.7	0.8
3	96.6	2.5	0.9	0.8

Powder mixture homogenization was performed into a double tronconic shaped homogenization device during 6-8 h, without producing shape or dimensional modification of the initial powder.

In order to determine the treatment features of iron-copper-graphite mixture cylindrical samples with 10 mm diameter, a weight of 16 g of powder uniaxial pressed are used. 6,52 g/cm^3 sample density was obtained with a 600 MPa pressing force. The sintering was performed inside a vacuum chamber that was introduced into an electrical oven with the maximum temperature at 1200 °C. The samples were sintered at 1120 ^{o}C for 1200 seconds in endothermic gas. Some sintered specimens were also processed by the steam treatment process at 580 ^{o}C for 1200 seconds.

To evaluate the fatigue limit ratio of an as-sintered specimen and a steam treated specimen of sample No.1 shown in Table 3, both the tensile and fatigue strength were evaluated (ASTM B925-08). The tensile test specimen was made by machining, and the tensile test was carried out at 0.008 mm/s. The fatigue test specimen was made by machining, and a fatigue test to evaluate the stress of non-breaking was done in a cycle of number 1×10^7 using the rotating-bending fatigue test.

The surface of a sintered specimen and a steam treated specimen in sample No.1 shown in Table 3 were measured for their stress by using X-rays and their residual stress was evaluated. The pore distribution of the sintered specimen and the steam treated specimen were observed using a optical microscope, and the pore roundness was measured by the expression (1) as an index for the spherical pores using an image analysis device.

$$D = 4\pi S/L^2 \tag{1}$$

In the expression, D stands for the pore roundness ($0 < D \leq 1$), S stands for the pore area, and L stands for the pore’s surrounding length. Through this calculation it can be seen that the pore becomes progressively spheroidal in shape the closer it gets to 1.

The fatigue limit ratio of the specimen with various amounts of graphite in the sample shown in Table 3 was evaluated by the same method as above.

The appearance of crack propagation in the tensile and fatigue test was observed with a optical microscope using the test sintered specimen. The specimen for observation of crack propagation in the fatigue test was prepared by interrupting the fatigue test in the cycle number 1×10^5 under the forecast stress to be broken in the cycle number 5×10^5 load.

3. RESULTS AND DISCUSSION

Figure 1 shows the tensile strength of the as-sintered specimen and the steam treatment specimen of sample No. 1 shown in Table 3. The results show that the steam treatment does not change the tensile strength that much, and the as-sintered specimen and the steam treated specimen showed almost equal tensile strength. Fig. 2 shows the fatigue strength of the as-sintered specimen and the steam treated specimen of sample No.1. The results show that steam treatment improves the fatigue strength compared to that of sintering. Fig. 3 shows the fatigue limit ratio of the as-sintered specimen and the steam treated specimen in sample No.1 calculated by Fig. 1 and 2. The results show that the fatigue limit ratio of the steam treated specimen is 0.46, and this result improves by 28% compared to 0.36 for the fatigue limit ratio of the as-sintered specimen.

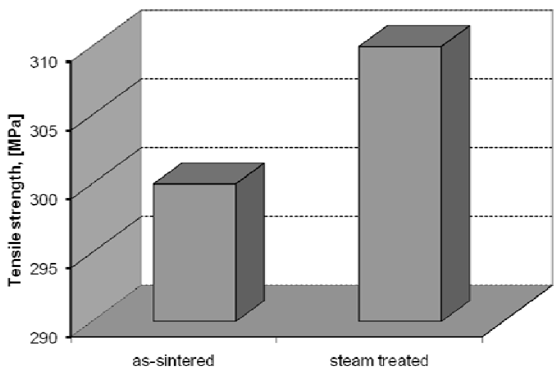


Figure 1. ***Comparison of tensile strength***

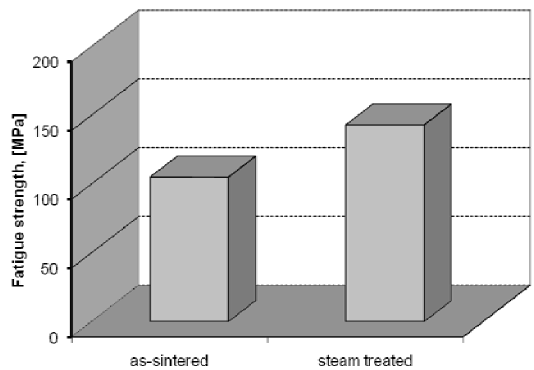


Figure 2. ***Comparison of fatigue strength***

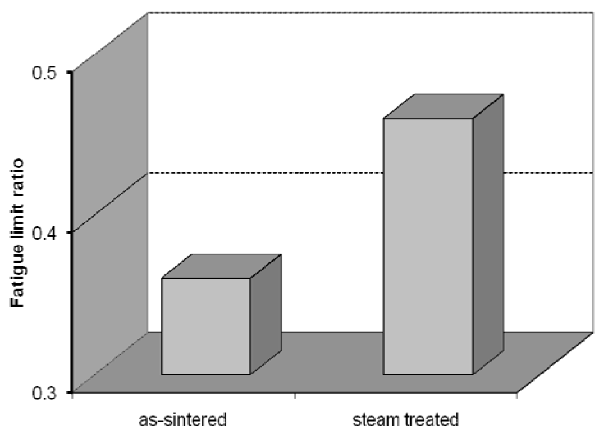


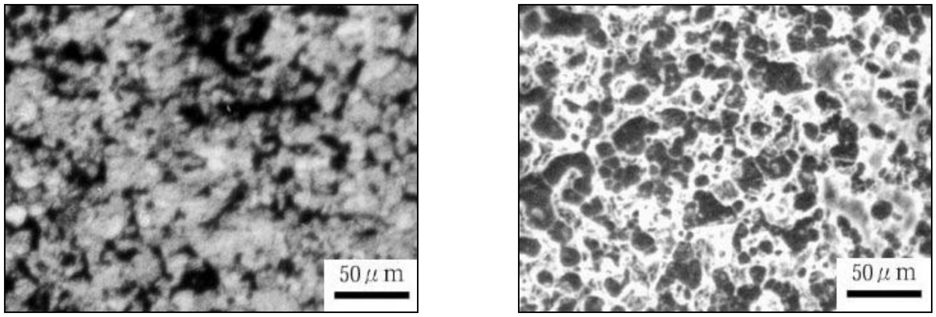
Figure 3. ***Comparison of fatigue limit ratio***

Figure 4 shows the pore distribution of the as-sintered specimen and the steam treated specimen in sample No.1. An oxide layer (Fe_3O_4) is formed on the outer part of the pores when the steam treatment process is used, the pores become spheroidal compared with that of the as-sintered specimen's pores. Table 4 shows the pores roundness and residual stress. The results show that the roundness of the pores increases by using the steam treatment process. Moreover, the stream treatment process increases the residual compressive stress.

Table 4. ***Comparison of pore roundness and residual compressive stress in specimen No. 1***

	As-sintered	Steam treated
Pore roundness	0.28	0.45
Residual compressive stress, [MPa]	43.0	76.5

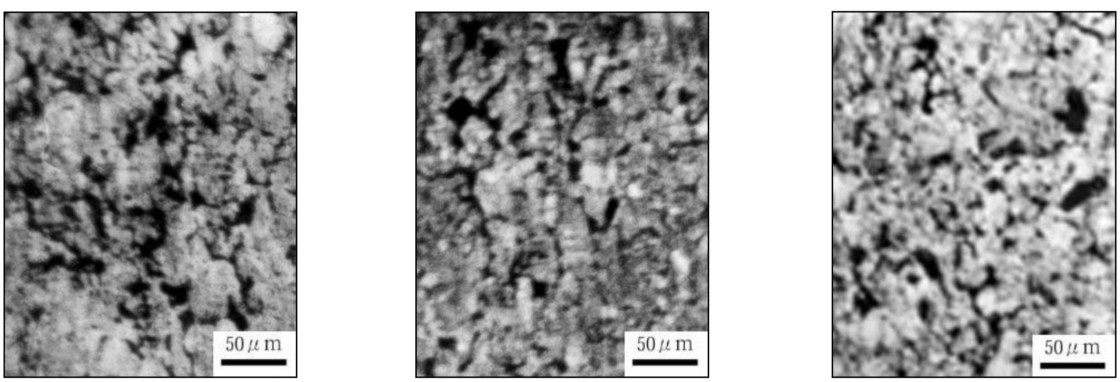
It therefore means that the fatigue strength improves by reducing the fatigue failure starting points by making the pores spherical and by adding residual compression stress in the steam treatment process. As mentioned before, the steam treatment does not change the tensile strength that much. As a result, the fatigue limit ratio of the steam treated specimen improves due to the steam treatment compared to that of the as-sintered specimen.



as-sintered steam treated

Figure 4. ***Pore distribution***

Figure 5 shows the microstructure of the steam treated specimen of the sample in Table 3. The results show that the pearlite increases as the amount of graphite powder is increased. Figure 6 shows the relationship between the tensile and fatigue strength of the steam treated specimen of samples in Table 3. The results show that the tensile strength increases as the amount of graphite powder is increased, but the fatigue strength does not change that much. Figure 7 shows the relationship between the amount of added graphite powder and the fatigue limit ratio of the steam treated specimen of samples in Table 3. The results show that the fatigue limit ratio decreases as the amount of graphite powder is increased.



0.5 mass% graphite 0.7 mass% graphite 0.9 mass% graphite

Figure 5. ***Microstructures of steam treated specimens***

Figure 8 shows the result of observed crack propagation in the tensile and fatigue tests. The crack propagation in the static (tensile) destruction test is observed in the ferrite and pearlite. On the other hand, it is observed that the crack propagation in the fatigue failure test makes a detour in the pearlite and to propagate in the ferrite. Therefore, it is suggested that the tensile strength improves as the pearlite area rate is increased because the crack of the static (tensile) destruction propagates in both the ferrite and the pearlite, on the other hand fatigue strength improves a little as the area rate of the pearlite is increased because the crack of the fatigue failure propagates mainly in the ferrite. Therefore, it is presumed that the fatigue limit ratio decreases as the pearlite is increased according to the increase in the amount of added graphite powder.

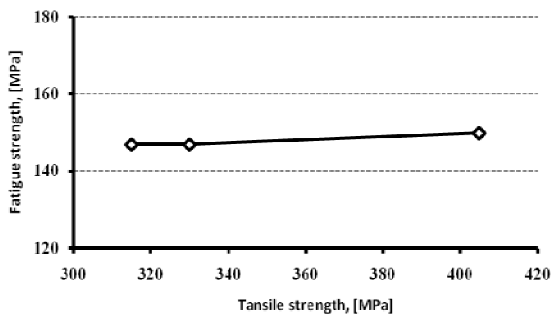


Figure 6. ***Relationship between tensile strength and fatigue strength of steam treated specimen***

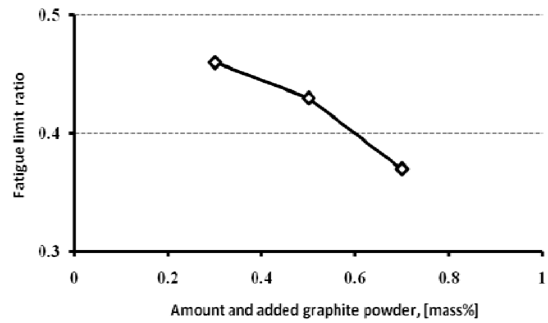
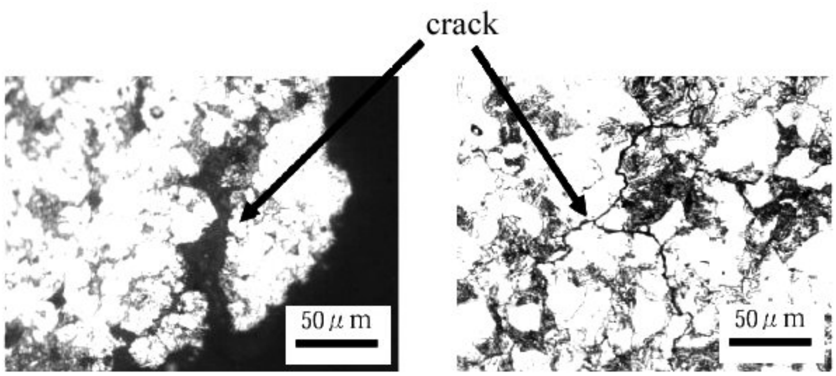


Figure 7. ***Relationship between amount of added graphite and fatigue limit ratio of steam treated specimen***



a) b)

Figure 8. ***Appearance of crack propagation in static (tensile) destruction (a), and fatigue failure (b)***

4. CONCLUSIONS

The improvement in the fatigue limit ratio was investigated by using an Fe-Cu-C material which is widely used as a P/M material. The conclusions of our research are following:

- the fatigue strength improves by making the spherical pore and by adding residual compression stress using the steam treatment process. However, steam treatment does not change the tensile strength that much. As a result, the steam treatment improves the fatigue limit ratio.
- the fatigue limit ratio improves as the amount of added graphite powder is decreased.
- mechanical fuse parts which use the newly developed P/M material with a high fatigue limit ratio were developed.

REFERENCES

[1] *** Metals Handbook, Ninth Edition, Powder Metallurgy, (1988), ASM, Ohio.
[2] Ivănuş, R.C., (2006), *Heat and termochemical treatments*, Universitaria Publishing House, Craiova.
[3] Surdeanu, T., Pernes, M., (1984), *Sintered Parts from Metal Powders*, Technical Publishing House, Bucharest.