

# Effect of Boronizing and Shot Peening in Ferrous Based Fecu-Graphite P/M Material on Fatigue Properties

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**Abstract:** Ferrous based materials manufactured by powder metallurgy (P/M) method are widely used in industry. These materials are very important in applications where no machining is required, can also be used as journal bearing material due to their self-lubricated property, and find applications in the medical industry. In this study, powder metal parts were manufactured from composites ferrous based FeCu-Graphite by P/M method. Fatigue test samples were carried out on manufactured samples receiving no treatment or boronizing treatment or boronizing+shot treatment. Fatigue properties of these parts were investigated by rotating bending fatigue test rig.

**Keywords:** Powder metallurgy, Boronizing, Shot peening, Fatigue.

## Introduction

Powder metallurgy is one of the methods used for used or semi-processed parts [1]. Because of higher melting temperatures of some metals, super alloy and hard metals must have been produced by powder metallurgy method [2, 3].

Mechanical properties of P/M parts depend on pore amount, distribution, type, size and form. As pore amount decreases, fatigue strength and the other mechanical properties improve [4]. Strength of machine parts is not as strong as that of conventional steels produced by powder metallurgy method [5]. In order to produce high density parts, high capacity presses or hot isostatic pressing method can be used. Thus, mechanical properties of P/M parts match mechanical properties of forging parts [1, 6]. Furthermore, powder metal materials exhibit different microstructure and density at various sintering conditions [7]. In addition to that, physical properties are affected from pore ratio. Porosity increase sound and vibration absorption property. Therefore, a significant portion of powder metallurgy products is designed to take

advantage of porosity into consideration [8]. Pore size and distribution are the most important parameters affecting mechanical properties [9, 10].

Boronizing is a thermo chemical surface hardening treatment that enriches the material surface in boron atoms via the diffusion of elemental boron into the surface of material in contact at high temperatures. Boronizing treatment is performed at temperatures of 950 °C for varying times between 1 and 10 hours. The characteristics of this boride layer depending on boronizing temperature, process time and properties of the boronized material. The boronizing elements placed into the heat resistant container and specimens are inserted into this powder [11]. The particle size of the powder is an important factor in the formation of the boride layer [12]. The advantages of boronizing treatment over the other types of surface hardening methods are that the surface layer is very hard, and no extra heat treatment is required after boronizing. The most important aim in boronizing is to achieve the desired hardness [13-15]. Fatigue resistance increases by boronizing. Therefore, boronizing can be applied to ferrous based P/M materials [1, 16].

Shot peening is an applied process where the surface of a machine part are treated with a lot of small spherical shot jet under controlled conditions. A compressive stressed layer occurs as a result of the non-homogeneous plastic deformation on metal material by shot peening. The aim of the shot peening is to improve fatigue, corrosion fatigue, and stressed corrosion of metal materials [17-20]. Improving fatigue properties of materials are important because machine elements are generally exposed to dynamic loads. One of the methods used to improve fatigue properties of materials is shot peening. Shot peening process can be applied to any metal based machine part. However, surface hardness and quality increases with shot peening in P/M materials due to a decrease in the number of pores [21-23].

In this study, powder metal parts were manufactured from composites ferrous based FeCu-Graphite by P/M method. Boronizing and boronizing+shot peening was applied to samples. Fatigue properties of these parts were investigated. In addition; microstructural properties of fracture surfaces were investigated.

## Experimental Studies

In this study, FeCu-Graphite composites 55x10x10 mm dimension were manufactured at 400 MPa pressure, 1120 °C sintering by P/M method. Non-boronized FeCu-Graphite (Group 1), boronized FeCu-Graphite (Group 2), boronized and shot peened FeCu-Graphite (Group 3) P/M materials were used. The chemical compositions of the materials used in the experiments are given in Table 1. Some basic properties of ASC 100.29 iron powder are shown in Table 2. Mechanical properties of ASC 100.29 iron powder are shown in Table 3. Chemical compositions of samples are shown in Table 4.

Material	C	Si	Mn	P	S	Fe
SAE 1020	0.2	0.25	0.7	0.04	0.05	Based

**Table 1.** Chemical composition of SAE 1020 steel disc (wt %).

Grade	Grade Dimension (µm)	Visible Density (g/cm <sup>3</sup> )	Flow (s/50 g)	H <sub>2</sub> Loss (%)	C (%)	Pressing (g/cm <sup>3</sup> ) (600 MPa)
ASC 100.29	20 - 180	2.96	24	0.8	0.002	7.21

**Table 2.** Some base properties of ASC 100.29 iron powder.

Tensile Strength (MPa)	Yield Strength (MPa)	A <sub>5</sub> %	Density ( $\rho$ ) (g/cm <sup>3</sup> )	Hardness (HV)
275	218	3.7	6.61	95

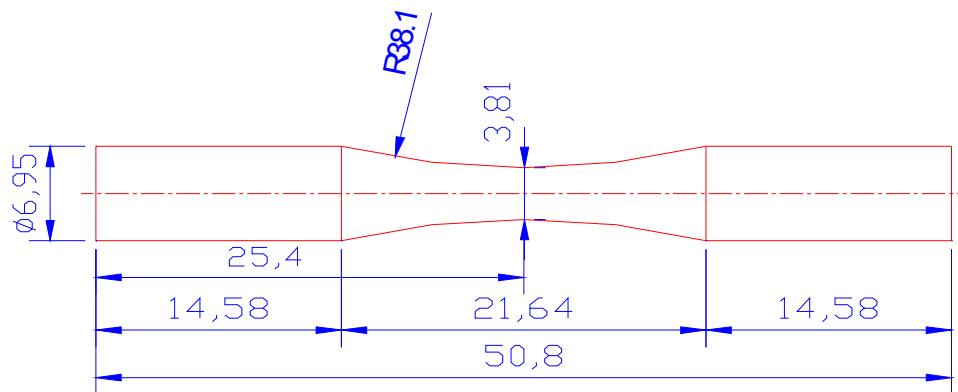
**Table 3.** Mechanical properties of ASC 100.29 iron powder.

Powder Quantity (wt %)	Graphite	Cu	Fe	Lubricant (Zn-Stearat)
	0.2	3	Based	0.8

**Table 4.** Chemical composition of samples (wt %).

The box boronizing method has been used for the boronizing process. The box was held in electric resistance oven for 4 h at 950 °C. At the end of the boronizing process, the box was cooled to room temperature and then the specimens were cleaned.

The microstructures were photographed using scanning electron microscope. Fatigue fracture surfaces were examined scanning electron microscope (Jeol JSM-6060). Dimensions of fatigue specimens are shown in Fig.1. Fatigue tests were applied to R=+/-1 under condition by using rotating bending fatigue test rig.

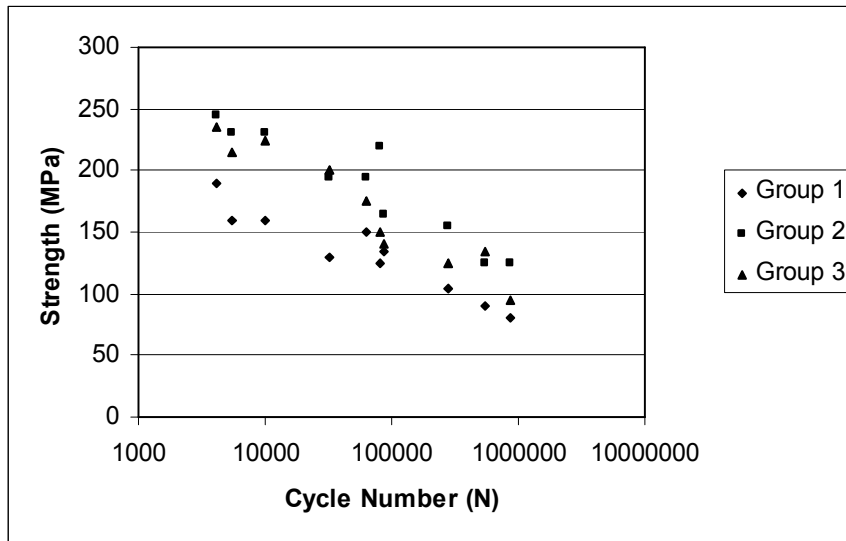


**Fig.1.** Fatigue sample.

## Results and Discussion

### Fatigue Properties

Results of fatigue properties were shown in Fig.2. Generally, fatigue properties of boronized specimens and boronized+shot peened specimens were higher than those of non-boronized specimens because of very hard boride layer.



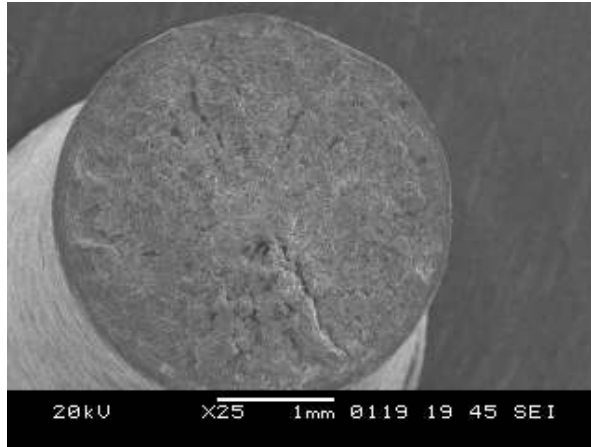
**Fig.2.** Curves of samples strength-cycle number (S-N).

Tunay et al [6], Varol and Saritaş [10], Saritaş et al. [13], Selver et al. [20], Orman [21], and Başaran [22] have examined fatigue properties of boronized or shot peened ferrous based P/M materials. They reported that boronizing and shot peening significantly improved fatigue properties in these materials.

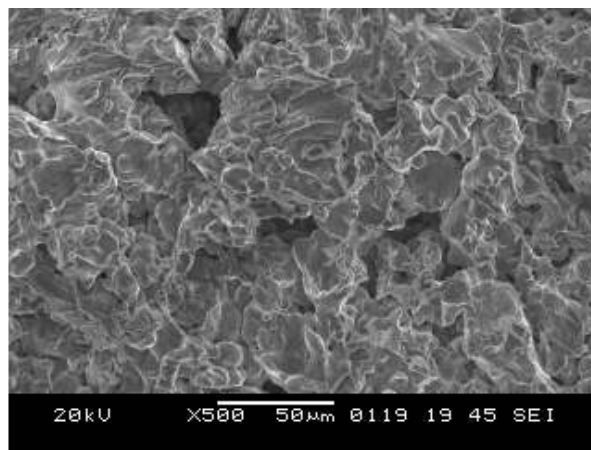
Harada et al. [25] investigated effects of microshot peening on surface characteristics of high-speed tool steel. They reported increase of hardness by applying shot peening at high temperatures. Chawla and Dang [26] investigated fatigue properties of porous sintered steels. They reported that fatigue strength increased with a decrease in porosity. Pariente and Guagliano [27] investigated fatigue properties of carburized and shot peened gear steels. Mahagaonkar et al. [28] investigated fatigue properties of SAE 1045 and SAE 316L steels. Zhang and Liu [29] investigated fatigue properties of Ti alloys. Bouraoui et al. [30] investigated fatigue properties metal parts. They reported that fatigue properties were improved with high residual stress by applying shot peening.

### Microstructural Properties

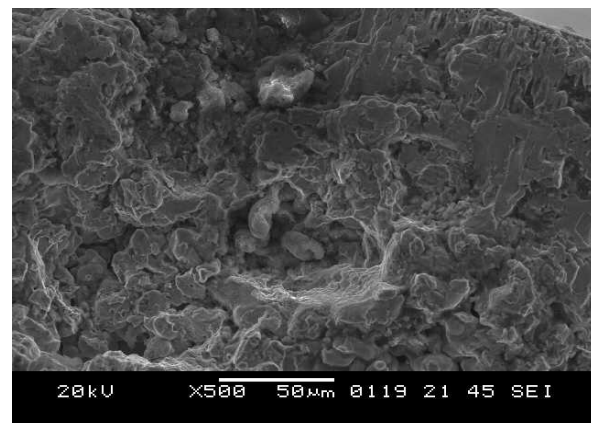
When microstructures of fatigue fracture surfaces of samples were examined by scanning electron microscope (SEM) (Figs. 3-6). Brittle fracture was observed in these PM samples due to porous structure. Thick, porous, and bright structure show brittle fracture of PM materials.



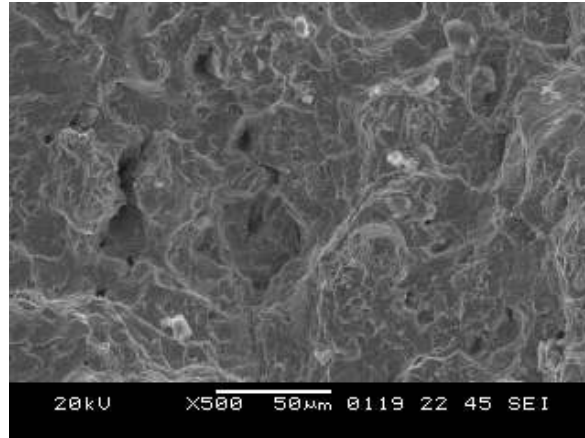
**Fig.3.** SEM microstructure of fatigue fracture surface of FeCu-Graphite composite (Group 1).



**Fig.4.** SEM microstructure of fatigue fracture surface of FeCu-Graphite composite (Group 1).



**Fig.5.** SEM microstructure of fatigue fracture surface of B-FeCu-Graphite composite (Group 2).



**Fig.6.** SEM microstructure of fatigue fracture surface of B+SP-FeCu-Graphite composite (Group 3).

Tunay et al [6], Varol and Saritaş [10], Saritaş et al. [13], Selver et al. [20], Orman [21], and Başaran [22] have examined microstructure properties of boronized or shot peened ferrous based P/M materials. They reported that boronizing and shot peening significantly improved microstructural properties in these materials because of reduction in porosity.

Tsuji et al. [24] investigated microstructural properties of plasma-carburized and shot-peened Ti-6Al-4V alloys. They observed a lot of uneven dimples on the surface of shot-peened carburized specimens. They reported that the dimple size and depth of the surface was very small due to a fine particle shot. Micro-cracks were not observed in the near surface. The carbon diffusion layer was observed as a thin whiter and brighter layer in the near surface region of shotpeened carburized specimen.

Harada et al. [25] investigated microstructural properties of microshot peening on surface characteristics of high-speed tool steel. They observed that the distribution of white rings on the surface of the peened workpieces. Chawla and Dang [26] investigated microstructural properties of porous sintered steels. They observed plastic deformation and crack growth due to changes in porosity.

## Conclusions

Based on the findings our study, the following conclusions can be drawn:

1. Fatigue properties of boronized specimens and boronized+shot peened specimens were higher than those of non-boronized specimens.
2. Brittle fracture was shown in PM materials.

## References

- Başaran, A., “Shot peening mechanical surfaces processes in P/M parts”, Süleyman Demirel University, Master Thesis, 2003.
- Bouraoui, C., Sghaier, R. B., Fathallah, R., “An engineering predictive design approach of high cycle fatigue reliability of shot peened metallic parts”, *Materials and Design* 30 (2009) 475–486.
- Bozkurt, N., “Surface hardening by boronizing in steels”, PhD thesis, Istanbul Technical University, Istanbul, Turkey (in Turkish), 1984.

- Çalışkan, C. "Powder Metallurgy", Istanbul Technical University, Under Graduate Thesis, 2000.
- Chawla, N., Deng, X., "Microstructure and mechanical behavior of porous sintered steels", *Materials Science and Engineering A* 390 (2005) 98–112.
- Demir A., Saritaş S., "Mechanical properties of powder metal steels", Akdeniz University,
- Douib, N., "Fatigue of inhomogeneous low alloy P/M steels" *Powder Metallurgy*, Vol. 32, No: 3, 209-214. pp. 1989. Engineering Faculty, Journal of Mechanical Engineering, (7) 1-13, 1993.
- evaluation under industrial processing conditions", *Materials Sci Forum*, 299-300, pp. 356-363, 1999.
- ferrous based PM parts", PhD thesis, Celal Bayar University, Manisa, Turkey (In Turkish), 2004.
- Göy, Z., "Boronizing", Master thesis, Istanbul Technical University, Istanbul, Turkey (in Turkish), 1984.
- Harada, Y., Fukauara, K., Kohamada, S., "Effects of microshot peening on surface characteristics of high-speed tool steel", *Journal of Materials Processing Technology* 201 (2008) 319–324.
- Justino, J. G., Bernardini, P. A. N., "Self-Lubricating Bearings: Microstructural and dimensional
- Kostilnik, T., "Wheel abrator Corporation", *Surface Engineering*, ASM Handbook Vol. 5, 1994.
- Lawley, A., "Atomization, The Production of Metal Powders", MPIF, Princeton, 1992.
- Mahagaonkar, S. B., Brahmanekar, P. K., Seemikeri, C. Y., "Effect on fatigue performance of shot peened components: An analysis using DOE technique", *International Journal of Fatigue* 31 (2009) 693–702.
- Mathuschka, A. G., "Boronizing", Carl Hanser Verlag, München Wien, 1980.
- Meriç, C., Sahin, S., Yılmaz, S. S., "Investigation of the effect on boride layer of powder particle Metal Society, s.147-157, Birmingham, 1981.
- Orman, Ş., "Investigation of effects of shot peening parameters on fatigue behavior of SAE 1020 steels", Gazi University, Master Thesis, 1999.
- Özsoy, A., "Improve of boron layer properties, transite zone and main matrix in boronized steel", P/M parts", Gazi University, I. Inter Conference of Powder Metallurgy, pp. 407-418, Ankara, 1996.
- Pariante, I. F., Guagliano, P. M., "Contact fatigue damage analysis of shot peened gears by means of X-ray measurements", *Engineering Failure Analysis* 16 (2009) 964–971.
- PhD thesis, Anadolu University, Eskişehir, Turkey (in Turkish), 1996.
- Saritaş, S., "Fatigue of surface treated powder forged steels", *Heat Treatment* 81, The
- Saritaş, S., Varol, R., Doğan, C., "The effect of shot peening on the fatigue properties of steels" *Euro PM 97*, Proce. of Advance Structural PM Component Production, Munich, Germany, October 15 – 17, 1995.
- Selver, R., Boylu, K. S., Varol, R. "Effect of shot peening and boronizing process on some properties of P/M steels materials", Süleyman Demirel University, *Journal of Science*, 8-1 (2004) 141-144.
- size used in boronizing with solid boron-yielding substances", *Materials Research Bulletin*, (35) 2165-2172, 2000.
- steels parts" 3. Conference of Powder Metallurgy, pp. 1221-1228, Ankara, Turkey (In Turkish), 2002.
- tribological properties in journal bearings", PhD thesis, Celal Bayar University, Manisa, Turkey (In
- Tsuji, N., Tanaka, S., Takasugi, T., "Effects of combined plasma-carburizing and shot-peening on fatigue and wear properties of Ti-6Al-4V alloy", *Surface & Coatings Technology* 203 (2009) 1400–1405.
- Tunay, R., F., Varol, R., Yılmaz, S., S., "Effect on mechanical properties of boronizing in P/M
- Turan, H., Saritaş, S., "Manufacturing of metal powder by gas atomization", *Machine design and production conference*, 21-23 Eylül 1994, METU, Ankara.
- Turkish), 2004.

- Ünlü, B. S., “Determination of usability of boronized ferrous based materials as bearing and
- Varol R., Sarıtaş S., “Effect of shot peening treatment on fatigue properties of ferrous based
- Varol, R. “Effect of different shot peening parameters of 2024 aluminum alloy on fatigue life” PhD thesis, Selçuk University, Konya-Turkey, 1990.
- Varol, R., Meriç, C., “Shot peening: Therocial and applications”, Eng. and Mech., 1992, 34 (405), 15-22.
- Yılmaz, S. S. “Effect on physical and mechanical properties of surface hardening treatments of
- Zhang, X., Liu, D., “Effect of shot peening on fretting fatigue of Ti811 alloy at elevated temperature”, International Journal of Fatigue 31 (2009) 889–893.