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Effect of electrolytic nickel coating on fatigue life of iron based powder metal parts

H. Çinici[1], K. Karacif[2*], F. Kafkas[1], R. Çitak[1]

[1] *Gazi University, Technology Faculty, Ankara, Turkey*
[2] *Hitit University, Faculty of Engineering, 19030 Çorum, Turkey*

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Abstract

Electrolytic coating is one of the methods mainly used to provide corrosion resistance for the powder metal parts. The coatings have strong effects on mechanical properties of coated parts as well as on surface properties. The other factor that affects the mechanical properties of powder metal (P/M) parts is density ratio. In this study the effect of electrolytic coating and density ratio on fatigue life of powder metal iron parts has been investigated. Commercially pure iron powders were pressed under 150, 200 and 250 MPa pressures. Specimens were sintered at 1100 ℃ in flowing argon atmosphere for 45 min. Some of the specimens were electrolytic nickel coated. Coated and uncoated specimens were fatigued in rotating bending under the same conditions. Also residual stress analysis was carried out on both kinds of specimens. It had been determined that electrolytic nickel coating increased fatigue life of P/M iron parts. It had also been determined that fatigue life increased with density ratio.

K e y w o r d s: nickel coating, powder metallurgy, fatigue, residual stress

1. Introduction

Powder metallurgy (PM) is a rapidly expanding technology for the manufacture of some small and complex shaped parts. The unique potential of PM process to provide uniform microstructures has increased the interest in the field of alloy and composite manufacturing. However, fatigue, wear and corrosion of PM products are the most common failure problems encountered in industry [1, 2]. The corrosion resistance of compacts made by PM process is normally poor, due to interconnected porosity that promotes corrosion in crevices and limits the use of such components [3, 4]. Porosity may interfere with treatments such as cleaning, pickling and electrodeposition, due to infiltration of aggressive solutions into the pores that must be blocked [5, 6]. Pores can be closed by electroplating. Electroplating has the advantage that it can impart features in addition to corrosion protection, fatigue and wear resistance. This potential can be maximized by plating two or more layers with different properties [1]. Electrolytic coating is one of the methods mainly used to provide corrosion resistance for the powder metal parts. Other usage fields of nickel coatings are to provide fatigue and wear resistance and an esthetic or metallic appearance on metal and polymeric materials [7–15]. Electrolytic nickel coating is a secondary or final process after pressing and sintering of the powder. The application of electrolytic nickel coating on P/M parts is generally similar to the conventional materials [1]. Electrolytic coating has some advantages such as high quality, uniform thickness and good adhesive.

In this study, commercially poor iron powder parts with varying densities were produced using different pressure. These compacts were sintered at 1100 ℃, in flowing Ar atmosphere for 45 min. Half number of specimens were electrolytic nickel coated. Residual stress analysis and fatigue tests were carried out on both coated and uncoated specimens and the effect of coating on fatigue life of P/M iron parts is discussed comparing the results.

2. Experimental procedure

Commercially pure, Höganas ABC 100.30 iron powder with $< 220\,\mu m$ dimension was used. The

*Corresponding author: tel: +90 364 227 45 33; fax: +90 364 227 45 35;
e-mail address: kubilaykaracif@hitit.edu.tr, kkaracif@hotmail.com

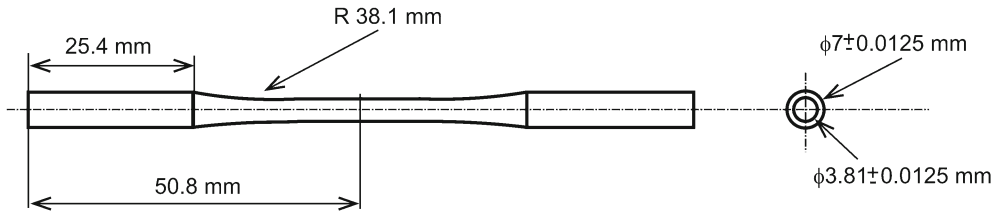


Fig. 1. Fatigue test specimen.

Table 1. Chemical analysis of iron powder (wt.%)

C	O-tot	Fe
0.002	0.04	Bal.

Table 2. Composition of polishing and coating baths and coating parameters

	Polishing bath	Coating bath
Na_2CO_3	20 g l^{-1}	
Na_2SO_3	22 g l^{-1}	
NaOH	50 g l^{-1}	
$NiSO_4$		200 g l^{-1}
$NiCl_2$		25 g l^{-1}
Boric acid		25 g l^{-1}
pH		4.5
Current density	4–6 A dm^{-2}	5 A dm^{-2}

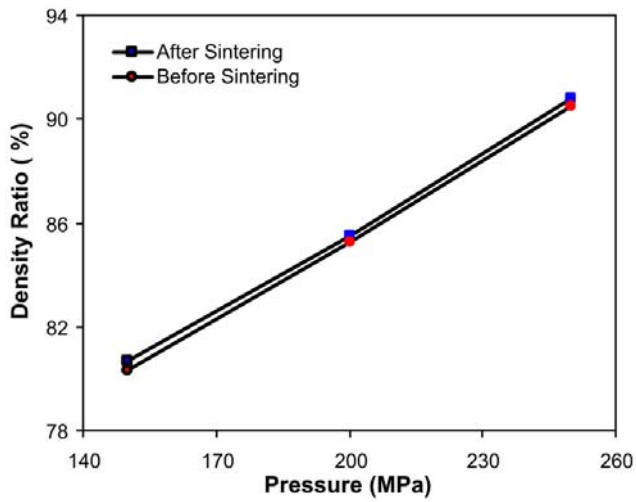


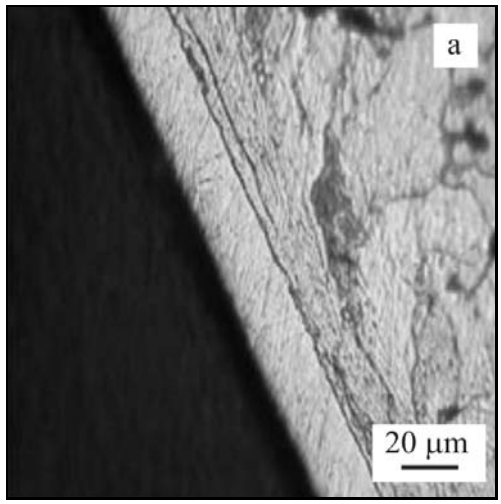
Fig. 2. The relationship between compacting pressure and density ratio of green and sintered specimens.

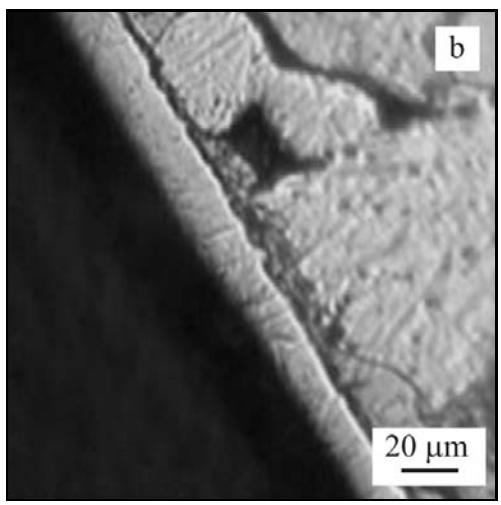
chemical analysis of Höganas ABC 100.30 iron powder is given in Table 1. The powder was pressed with a dimension of 10 × 10 × 66 mm^3 under 150, 200 and 250 MPa pressure to produce specimens with different density. The specimens were heated up to 1100 ℃ with a 5 ℃ min^{-1} heating speed and sintered in this temperature in flowing Ar atmosphere for 45 min. Then the specimens were cooled down to room temperature in the furnace. Specimens then were machined with a CNC lathe in the shape of fatigue test specimen. The shape and dimensions of the machined specimens (rotating bending fatigue test specimens) are given in Fig. 1. These specimens were ground to 1200 sandpaper to remove surface roughness. Half number of specimens was Ni coated in a bath the composition of which is given in Table 2. Table 2 also includes the composition of chemical polishing bath and coating parameters. After coating the samples were taken out of bath and then washed and dried.

Fatigue test specimens were tested under 77.5 MPa load with a speed of 2995 rpm. Residual stress analyses were carried out on the coated and uncoated specimens. Average values of five specimens were used for fatigue life and residual stress analyses. Residual stress distribution versus distance from the specimen surface was evaluated by using layer removal method. Layer removal from the specimen surface was carried out via the electrochemical polishing. In this method, removing of the successive layers from specimen surface release the residual stresses and they result in a deformation of specimen. Once a deformation on the specimen is obtained, the analysis and computation for estimating residual stress are most simple. Hence, the deformation of specimen is recorded against the electrochemical layer removal thickness and residual stresses can be calculated in the computer.

3. Experimental results and discussion

Density ratio of the specimens versus compacting pressure is given in Fig. 2. As seen in Fig. 2, density ratio increased with increasing compacting pressure. Thus porosity ratio decreased with increasing pressure. 91 % density ratio was provided under 250 MPa load while 80 % density ratio was provided under 150 MPa load. After sintering, little increase in density ratio was provided as seen in Fig. 2. This increase was higher in specimens with higher porosity ratio. Cross sectional micrographs of the coated specimens





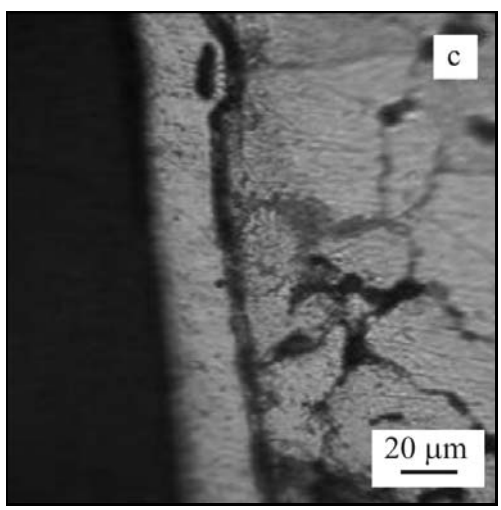
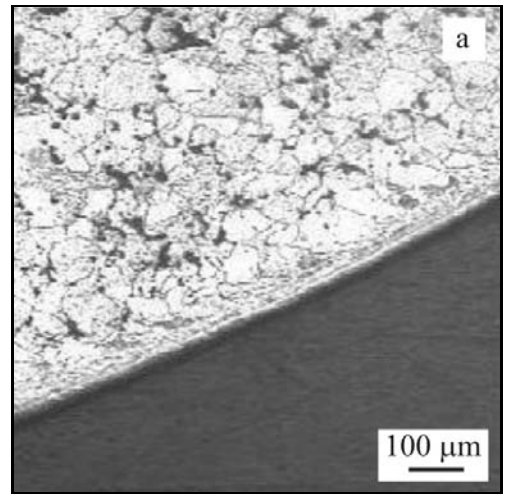
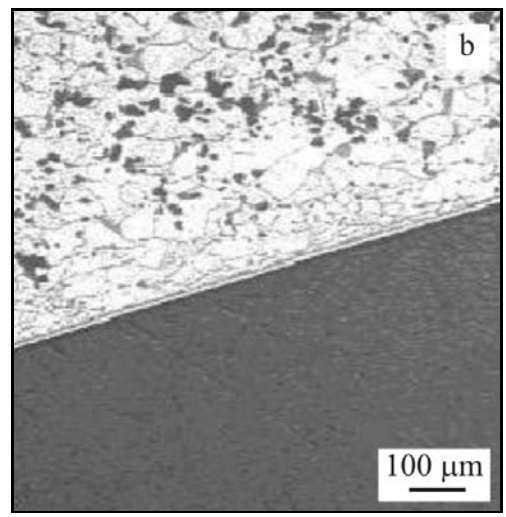


Fig. 3. Cross sectional micrographs of the coated specimens: a) 9 % porosity, b) 15 % porosity, c) 20 % porosity.





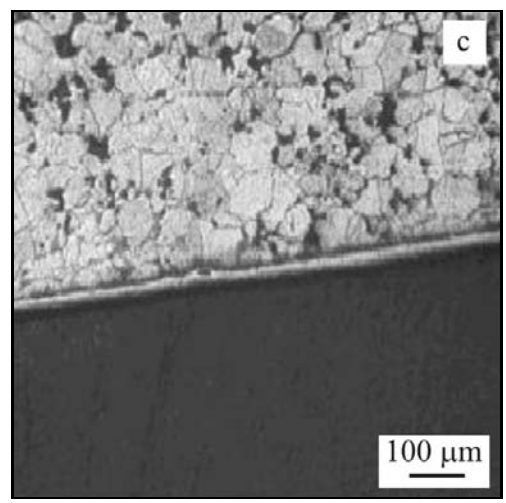


Fig. 4. Pore shape and distribution of the coated specimens: a) 9 % porosity, b) 15 % porosity, c) 20 % porosity.

are given in Figs. 3 and 4. It is seen in Figs. 3 and 4 that porosity ratio has an effect on coating quality. In specimens with low porosity ratio, distribution of pores is more uniform and pore size is small. In the specimens, the coating joins better with the base metal (Figs. 3a and 4a). Contrarily in specimens with high

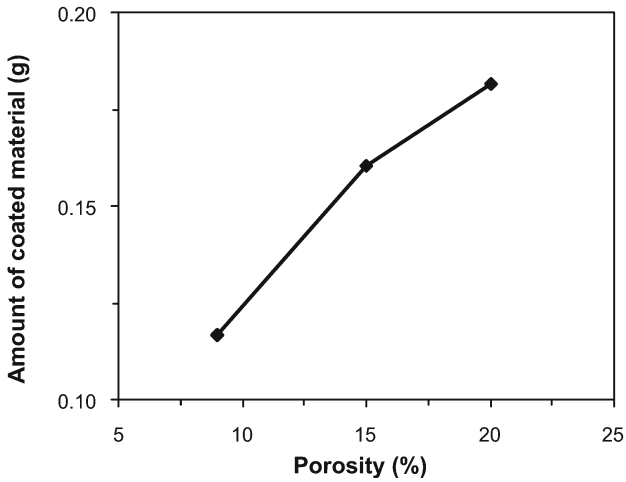


Fig. 5. Amount of coated materials against porosity.

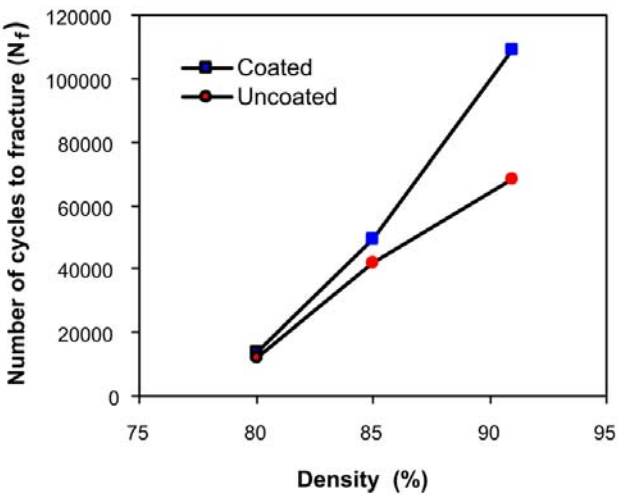


Fig. 6. Fatigue life versus density ratio of coated and uncoated specimens.

porosity ratio, pores join with each other, pore size is large and there are pores next to interface. In the specimens, adhesion between coating and base metal was relatively bad (Fig. 3b,c and Fig. 4b,c). This result is convenient with the literature [16]. The coating thicknesses were defined by microstructural investigations. As seen in Fig. 3, coating thicknesses are about 30 μm. All the specimens have almost the same coating thickness. Although coating thicknesses were the same there were differences among the amount of coating materials (Fig. 5). Amount of coated materials increased with increasing porosity ratio. This is because of pores open to the surface that increased the coated surface area. Thus amount of coated materials was increased although coating thicknesses were the same. Some authors reported the same results [16].

Fatigue life of the coated and uncoated specimens

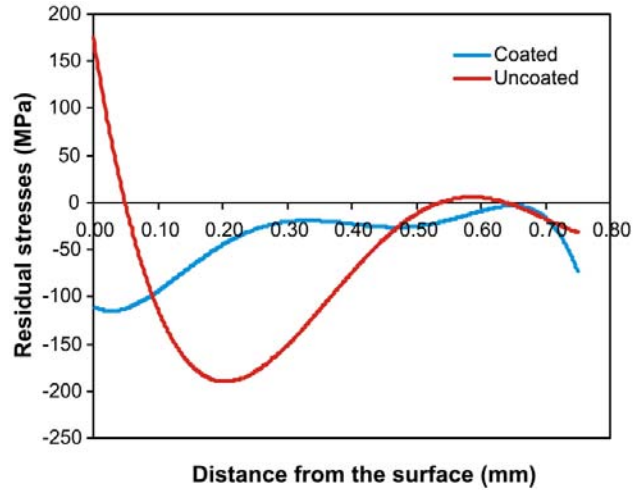


Fig. 7. Residual stress analysis of coated and uncoated specimens.

is given in Fig. 6. As seen in Fig. 6, fatigue life of the specimens decreases with increasing porosity ratio. Electrolytic nickel coating increased fatigue life of the coated specimens. This increment also changes with the porosity ratio. In specimens with 20 % porosity the increment is about 14 % while it is 61 % in specimens with 9 % porosity.

As widely known, fatigue is related to especially surface cracks and sharp inner pores and defects. It also depends on existence of tensile or compressive stresses on the surface of the parts [17, 18]. Residual stress analysis is given in Fig. 7. Figure 7 reveals that tensile stress which is high on the surface and decreased to center is present on the uncoated specimens. Contrarily, compressive stress is present on the surface of coated specimens. As seen in Fig. 6, electrolytic nickel coating increases the fatigue life of P/M iron parts. Increment in the fatigue life of the coated specimens can be explained in a few mechanisms. First of all, coating removes or covers the pores that initiate fatigue cracks on the surface. In specimens with the low porosity better coating properties are provided. Thus coating improves the fatigue life of low porosity parts much more. In high porosity coating cannot remove or cover all the pores, or there are defects on the coating itself. Compressive stress on the surface of the coated specimens also prevents or retards initiating of fatigue cracks on the surface.

It is known from the literature that fatigue strength depends mostly on residual stresses and hardness on the surface and under surface [19]. Experimental results show that electrolytic coating has important effect on preventing crack initiating. There is weak bound between substrate and coating preventing diffusing each other and known as delamination [19]. Also because of this delamination, transferring of fa-

tigue cracks that take place in coating to the substrate is delayed.

4. Summary and conclusion

From the aforementioned experiments and results the following conclusions can be drawn:

1. Porosity ratio affects the electrolytic nickel coating quality on P/M iron parts.

2. Better coating quality can be provided with low porosity.

3. Compressive stress takes place on the surface of coated parts.

4. Thus electrolytic nickel coating improves the fatigue life of the P/M iron parts.

5. This improvement is much higher on low porosity parts than that on high porosity parts.

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