Electropolishing Iron-Cobalt-Vanadium Laminate Stacks to Improve Performance of Electrical Machinery

By

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An electropolishing method was developed for electrical machinery laminated stacks of a 49% Fe, 49% Co, 2% V alloy. The method removed the metal most rapidly at the laminate interfaces. The glue between the laminates was washed away as the metal was removed. A mixture consisting of phosphoric and hydroxyacetic acids and ethylene glycol produced an unpitted polished surface. The electropolishing technique was especially effective at removing metal on the laminated stack surface that caused electrical shorting of the laminates.

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Overview

Most electrical machinery that uses alternating current is fabricated from metal that is built up from thin laminates. Between the laminates are electrical insulating layers which prevent electrical resistance heating and power loss.

Two final manufacturing operations on parts made from laminate stacks can ruin the electrical insulation between the laminates. These are grinding which smears the laminates together on the surface, and electro discharge machining, which melts the laminates together on the surface. An electropolishing method was developed for laminates of an alloy of 49 % Fe, 49 % Co and 2 % V. It removed just the very thin layer of surface metal that was responsible for the interlaminate shorting.

Theoretical Background

Electropolishing is so effective because electric charges accumulate at protuberances on the surface¹. This concentrates the metal removal at the roughest ridges, quickly polishing them down until the surface is flat.

The element atoms with the lower electrochemical potential will be removed from the surface most quickly by electropolishing. In particular, the electrochemical potentials of the two major elements in the alloy are shown in Table 1 and cobalt has the lowest potential. Electropolishing will leave the surface layer iron rich, but that is acceptable in this case since the magnetic saturation level of the alloy increases up to seventy-three percent iron³.

Table 1. Electrochemical potential of major elements in alloy studied.

| Element | Electrochemical Potential |
|---------|---------------------------|
| Iron | 0.441 V |
| Cobalt | 0.290 V |
| | |

The electrolyte formulation affects the quality of the electropolished surface. Inhibitors of acid corrosion such as ethylene glycol and surfactants help improve the electropolished surface quality when added to the mixture⁴. The ASM handbook recommends a solution of ninety percent acetic acid and ten percent perchloric acid for electropolishing iron cobalt alloys⁵. However this is for preparation of metallographic samples for microscopy. Different compositions are used by commercial electroplaters which have to consider environmental and cost concerns when choosing all chemicals.

Procedure

The electropolishing for this project was performed in two trials, both on the same laminated rotor made from 0.1 mm (.004 in.) thick sheets of 49 % Fe, 49 % Co, 2 % V alloy. In the initial attempt, the process utilized an electrolyte composed of phosphoric and sulfuric acid. With this mixture the material removal was insufficient and nonuniform, and the surface was pitted. The second electrolyte was composed of phosphoric acid, ethylene glycol and hydroxyacetic acid. With this mixture electropolishing produced an excellent smooth surface.

To determine the effectiveness of electropolishing, both optical and scanning electron microscopy were used. The electropolished OD surface was examined directly with the scanning electron microscope. A section was cut out of the laminated rotor as shown in Figure 1 and studied under the optical microscope. The area of the cross section near the rotor OD was particularly of interest since a view of the cross section there showed a cross section of the electropolished surface.



Electropolished OD observed with scanning electron microscopy

Cross section observed with optical microscopy

Fig. 1. Electropolished Rotor Laminate Stack.

Discussion of Results

The optical micrographs in Figure 2 show cross sections through the rotor OD after electropolishing with the second electrolyte mixture which included ethylene glycol and hydroxyacetic acid. In the left micrograph, a single laminate separated by thin layers of adhesive is visible. The right micrograph is a magnified view at the OD surface where the two laminates meet. The microstructure of the alloy studied consists of a bulk phase in which is dispersed a fine strengthening precipitate². The bulk alpha phase and the precipitated phase are both visible.

These micrographs show there is no smeared metal left from the grinding operation on the OD after electropolishing. The laminates are distinctly separated on at the surface. Where the laminates meet, there is a small dip on the electropolished surface because the electropolishing technique removed the metal at the sandwich interface at a faster rate.



Fig. 2 Left: OD surface electropolished. Cross section 400 X Right: OD surface electropolished. Cross section 1000 X

Scanning electron micrographs of the rotor OD surface are shown in Figure 3. The one at the top left shows the surface immediately after it was



Fig. 3. Scanning electron micrographs of rotor OD. Top Left: The rotor lamination OD after grinding. Top Right: After polishing with electrolyte containing sulfuric acid. Bottom Center: After polishing with electrolyte containing ethylene glycol and hydroxyacetic acid.

ground. Grinding has smeared the laminates surfaces together so that no individual laminates could be distinguished. The micrograph in Figure 3 (top right) shows the surface after electropolishing with the first electrolyte mixture of phosphoric and sulfuric acids. The thin adhesive layers between the metal laminates are visible.

Insufficient metal was removed to completely remove the interconnecting metal on the surface, but the laminates were visible which was encouraging. Figure 3 (bottom middle) shows the rotor OD surface after it was electropolished again but this time with the mixture of phosphoric and hydroxyacetic acids and ethylene glycol. The laminates are completely separated with no smeared metal left. The rough material in the grooves is the epoxy glue between the laminates. A trough is observable at the grooves between the laminates.

The edge effect of charge accumulation probably helped by causing the material, near the laminate edges to be removed at a faster rate. This effect is illustrated in Figure 4. The corner edges had a higher voltage due to charge accumulation. This caused more anodic dissolution exactly where it was needed the most to remove smeared metal in between the laminate edges.



Fig. 4 - High charge at laminate corners.

A very highly magnified SEM micrograph of this electropolished surface is shown in Figure 5. The surface is very smooth. The pitting shown is not typical. The smooth surface around the pit is typical.

Conclusions

Electropolishing removed the thin layer of ground metal on the surface of the rotor laminate stack. Both optical and electron microscopy clearly showed the laminates were distinct with no metal between them after electropolishing.

The scanning electron microscope showed the electropolished surface to be very smooth, despite the fact that the microstructure contained two phases with different concentrations of iron and cobalt. Precisely controlled removal of a very thin layer of metal was achieved.

The glue between the alloy laminates was washed away as the metal was removed. The combination of the effect that polished more of the metal away at the corners and the washed away glue left very shallow troughs between the laminates.



Fig. 5. A 5000 X view of the final electrolished surface.

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