Improvement of corrosion fatigue strength of materials by various surface treatments

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Abstract

In this paper it is summarized on improvement of corrosion fatigue strength of materials by various kind of surface treatments mainly based upon the author's experimental data. It is described on the effect of synthetic resins, thermal-sprayed coatings and ion plating on corrosion fatigue strength of structural materials. The emphasis is focussed upon the tar epoxy resin coating for ship structural steels and thermal-sprayed coatings for machine structural steels. The mechanism of the improvement of corrosion fatigue strength of materials by surface coatings are also described. It can be concluded that the improvement of corrosion fatigue strength is not effective when an interception effect disappear due to the breakage or degradation of the tar epoxy resin coating. It can also be concluded that the effective thermal-sprayed coating to improve corrosion fatigue strength should be of very low porosity and firmly adhesive to the base metal.

1 Introduction

Surface treatment is one of the effective method to improve corrosion fatigue strength of structural materials in service environments. So far many papers have been reported on the effect of surface treatments such as metal coating [1] and shot peening [2] to improve corrosion fatigue strength of steels. The coating effect is expected to retard corrosion fatigue crack initiation and/or decelerate corrosion fatigue crack propagation rate of materials. In this paper it is briefly reviewed on the effect of synthetic resins such as epoxy resin coating and tar epoxy resin coating, thermal-sprayed coatings such as plasma sprayed coatings and cermet coating and ion plating for various structural materials mainly based
upon the author's experimental data.

2 Effect of synthetic resins on corrosion fatigue strength of various materials

2.1 Effect of epoxy resin coating on environmental fatigue strength of various materials

Since Gilde et al. [3] have reported on the effect of an epoxy resin coating over the weld reinforcement in improving the fatigue strength of welded joints, this effect has been confirmed by other experiments [4] [5] [6]. Two factors were to be considered: first the protective effect of the coating against atmosphere and, secondly decrease the stress concentration at the toe of the weld reinforcement. It was clarified that oxygen and relative humidity in air significantly affect the fatigue strength of steels and aluminum alloy [7] [8]. While fatigue crack initiation was not affected by the atmosphere, the crack propagation rate was more rapid in atmosphere which contains oxygen and water vapor. Therefore the effect of epoxy resin coating in improving the fatigue strength of welded joints can be strongly attributed to this protective effect against air. In fact the fatigue crack propagation rate was decelerated by epoxy resin coating with 2 mm thickness as shown in Fig.1 [7]. In this figure it is also demonstrated that the coating effect disappear if the

![Fatigue crack propagation rate](image-url)

Figure 1 Crack propagation rate of plastic coated mild steel in air (Masumoto et al.) alternative bending stress: 217.7MPa

Note: ▲ and ○ show break of coating
coating should break. In this experiment it was clarified that the coating effect was ineffective by the epoxy resin coating with thickness less than 1.5mm. It was concluded that the most effective coating among the synthetic resins was epoxy resin coating cured with poly-amid and had poor air permeability, flexibility and good adhesion for metal surface [9].

2.2 Effect of tar epoxy resin coating on corrosion fatigue strength of ship structural steel

The ship ballast tank members are exposed to the atmosphere with high temperature and high relative humidity or sea water environment. Therefore the tar epoxy resin coating has been applied to ballast tank members against these aggressive environment. In order to evaluate the ballast tank life an evaluation of an effect of tar epoxy resin coating and its thickness on corrosion fatigue strength is absolutely necessary. Fig.2 shows the effect of 200μm tar epoxy resin coating on the corrosion fatigue strength of the ship structural steel KA32(TMCP) plate notched specimen by push-pull fatigue testing [10]. It is clear that the effect of tar epoxy resin coating is observed in lower nominal stress range. The lower the nominal stress range the coating effect increased.

![Figure 2 S-Nf curve for tar epoxy coated notched specimen in artificial sea water (Kobayashi)](image-url)
Surface Treatment

It can be also observed that the thicker the coating thickness the longer the fatigue life is [Fig.3]. It was observed that corrosion pits initiated on the base metal after breakage of coating caused by deterioration of the tar epoxy resin. Then corrosion fatigue crack initiated and propagated in association with

![Figure 3 Relation between tar epoxy coating thickness and number of cycles to failure (Ebara et al.)](image)

Impedance-time curve for tar epoxy resin coated specimen with 50 to 300 μm thickness is shown in Fig.4. Impedance of tar epoxy resin coated with 50 μm thickness drops tremendously after few days exposure into an artificial sea water. The same phenomenon is seen on 100, um tar epoxy resin coated specimen. While the impedance of 200 μm and 300 μm tar epoxy resin coated specimen never drops after exposure for 6000 hrs. The impedance drops slightly after 10^4 hrs. exposure and the dropping rate is not prominent. Thus it can be mentioned that tar epoxy resin deteriorate due to the change of water absorption. In this study it was also observed that the deterioration of the tar epoxy resin coating occurs at the notched area influenced by repeated stress. And impedance decrease of the notched portion was bigger than that of a plane portion (Fig.5). From afore mentioned results the mechanism of the deterioration of the tar epoxy resin coating can be concluded as follows. In higher stress level corrosion fatigue crack initiate earlier at the notched area where stress concentrate and an improving effect of corrosion fatigue strength is not expected when an interception effect disappear. The lower the stress an improving effect becomes to be recognized by an interception effect due to the difficulty of crack
Figure 4 Impedance/Time curve for tar epoxy coated specimen with various coating thickness, Artificial sea water, 200Hz [Ebara et al.10]

Figure 5 Impedance/number of cycles curve for tar epoxy resin coated fatigue test specimen with 50 μm coating thickness [Ebara et al.10]
initiation on the coating. However an improving effect becomes to be small when water absorption rate increases and the coating deteriorate as times goes by. Effective coating thickness is an extent of 200 μm.

3 Effect of thermal-sprayed coating on corrosion fatigue strength of steels

Fig. 6 shows plasma-sprayed coating effect on the corrosion fatigue strength of 13Cr stainless steel [12]. In this experiment rotating bending corrosion fatigue tests were conducted on WC-Co, ZrO₂, Cr₃C₂, Co-Cr-Ni-W plasma-sprayed specimens in 3% NaCl aqueous solution at a testing speed of 60Hz. The WC-Co and ZrO₂ coating with low porosity improved corrosion fatigue strength at 10⁷ cycles by about 70%. While no improvement of corrosion fatigue strength was observed by the Cr₃C₂ and Co-Cr-Ni-W coatings with relatively high porosity. In these specimens corrosion fatigue cracks initiated from corrosion pits at the surface of the base metal and propagated predominantly through the intergranular path. Corrosion fatigue mechanism of the plasma sprayed 12Cr stainless steel in 3% NaCl aqueous solution can be schematically depicted as shown in Fig. 7.

![S-N curves of various plasma sprayed specimens in air and in 3% NaCl aqueous solution](image)

Figure 6 S-N curves of various plasma sprayed specimens in air and in 3% NaCl aqueous solution [Ebara et al.12]

It was also found that the corrosion fatigue strength of the WC-Cr-Ni cermet thermal-sprayed specimen with 100 μm thickness was about three times larger than that of the SKD11 base metal at 2x10⁷ cycles in 2 mass % ZnSO₄ aqueous solution [Fig.8] [13]. The effective thickness of the WC-Cr-Ni cermet thermal-sprayed coating to improve the corrosion fatigue strength of SKD11 steel was about 100 μm [Fig.9]. In this case the principal cause of the improvement of the corrosion fatigue strength of steel by thermal-sprayed WC-Cr-Ni cermet is the
insulation of SKD11 steel surface from the permeation of ZnSO₄ aqueous solution. Impregnation of fluorine-contained resin into the thermal-sprayed WC-Cr-Ni cermet was found to be effective to improve corrosion fatigue strength of SKD11 in lower stress region.

Figure 7 Schematic illustration of corrosion fatigue mechanism of plasma-sprayed 13Cr stainless steel in 3% NaCl aqueous solution [Ebara et al.]

Figure 8 S-N curves of WC-Cr-Ni thermal-sprayed specimen in 2 mass% ZnSO₄ aqueous solution [Ebara et al.]
4 Effect of Ion plating on corrosion fatigue strength of steels

The ceramic coating has been applied to the substrate material by new techniques, such as chemical vapor deposition (CVD), or physical vapor deposition (PVD), the latter method being more precise than the former.

The compressor drive turbines for petrochemical plants are currently expected, from the stand point of saving energy and maintenance, to withstand long term continuous operation of more than 5 years. Cr-TiN multilayer coating was successfully applied for actual turbine moving blade to prevent drain erosion[14].

In order to evaluate the mechanical properties of Cr-TiN multilayer coating fatigue and corrosion fatigue tests were also conducted on Cr-TiN coated specimens in air and in 3%NaCl aqueous solutions. It was observed that fatigue and corrosion fatigue strength of Cr-TiN multilayer coated specimen is almost same as that of the base metal[15]. It can be concluded that Cr-TiN multilayer coating is an effective surface treatment for turbine blade against drain erosion without causing a decrease in its fatigue strength which is frequently encountered with stellite soldering. Improvement of corrosion fatigue strength can be expected if corrosion resistant coating without pinhole should be developed.
5 Concluding remarks

In this paper it is briefly summarized on the effect of surface treatments to improve corrosion fatigue strength of structural materials. It can be concluded that the effective coating to improve corrosion fatigue strength should be of very low porosity and firmly adhesive to the base metal. However corrosion fatigue is a time dependent phenomenon. Therefore more microscopic studies are needed to develop a corrosion resistant coating in surely improving long-term corrosion fatigue strength of materials.

References


