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EFFECT OF COMPRESSIVE RESIDUAL STRESS FOR CORROSION PROPERTY OF SUP-9 STEEL USING AS SUSPENSION MATERIAL

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ABSTRACT–One of the useful technologies for light-weightening of components required in the automobile and machine industry is to use high strength materials. To improve material properties, the carbonizing treatment, nitrifying treatment, and shot-peening method are representatively applied. However, the shot-peening method is generally used to remove surface defect on steel and to improve the fatigue strength of the surface. Benefits of shot-peening are increasing resistance against fatigue, stress corrosion cracking, fretting, galling, erosion and closing of pores. In this paper, the effect of shot-peening on the corrosion of SUP-9 steel immersed in a 3.5% NaCl solution and corrosion characteristics from heat treatment during the shot peening process has been investigated. The immersion test was performed on four kinds of specimens. Corrosion potential, the polarization curve, residual stress etc. Were analyzed from the experimental results.

KEY WORDS : Shot peening, Corrosion, Corrosion potential, Corrosion current, Surface roughness, Corrosion rate

NOMENCLATURE

mdd : measure of corrosion velocity
Ecorr : corrosion potential
Icorr : current density
SCE : saturated calomel electrode

1. INTRODUCTION

The modes of transportation such as automobiles, ships, rolling stock, airplanes and others made use of light-weight materials more and more in accordance with the trends of weight reduction. Consequently, they have decreased the use of steel material. The carburizing, nitriding, high frequency surface hardening, and residual compression stressing of the surface by shot peening has made high-strength and light-weight steel products. These days, the shot peening technology that is high value added and clean technology has been widely used (Bae *et al.*, 2005). However shot-peening related research has mostly focused on improvement of the fatigue feature (Tange and Takamura, 1990) and use in serious corrosion environments has gradually increased, demanding corrosion environment to demand research on corrosion-making devices.

This study investigated corrosion feature under corrosive of the material in corrosive environment with shot-peening of SUP-9 steel, used mainly for suspension systems of automobiles, and it examines relations between the corrosion-making device and residual compression stress. And, heat treatment generally make change in the oxide and construction to accelerate corrosion and create unstable. However, shot peening with heat treatments was found to improve fatigue strength, and improvement (Cheong *et al.*, 2001) in corrosion resistance has not been found under corrosive environment.

Therefore, this study examines that the influence of heat treatment of shot-peening upon residual compression stress and corrosion feature. The purpose of the study is to reduce economic loss caused by corrosion, to examine the influence of SUP-9 steel upon corrosion pit making in order to construct a database of optimum design techniques for suspension systems, and to reduce expenses by light weight design.

2. SPECIMENS AND EXPERIMENTAL METHOD

2.1. Specimens

In this experiment, JISG SUP-9, spring steel used for suspension system in automobiles as well as rolling stock, was used, and its chemical components are shown in Table 1.

The test piece was a flat plate having dimension of $50 \times 60 \times 12.5$ mm as shown in Figure 1, and it was classified into four types depending upon heat treatment and shot peening, for instance, NonHT & unpeened, HT & unpeened, NonHT & shot-peened and HT & shot-

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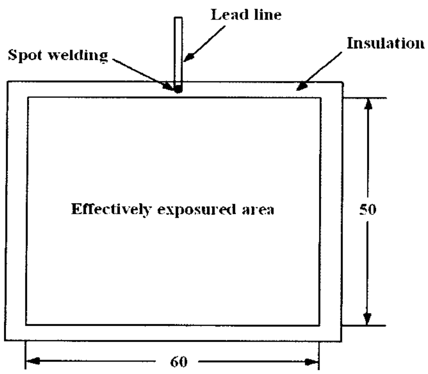


Figure 1. Shape and dimensions of specimen.

Table 1. Chemical compositions of SUP-9 steels [wt%].

Material	C	Si	Mn	P	S	Cr	V
JISG SUP-9	0.56	0.25	0.84	0.016	0.009	0.88	–

peened.

The heat treatment was made in a 970°C of continuous gas furnace for 20 minutes as shown in Figure 2, quenching was made in 40°C~80°C quenching oil after the 20 minutes of heating, and the tempering was done in a 490°C continuous tempering furnace for 80 minutes. Table 2 shows the mechanical properties of the test piece after the heat treatment. The hardness indicates the Rockwell hardness at a depth of 100 μm from the surface (Ball diameter: 10 mm, weight: 300 kgf).

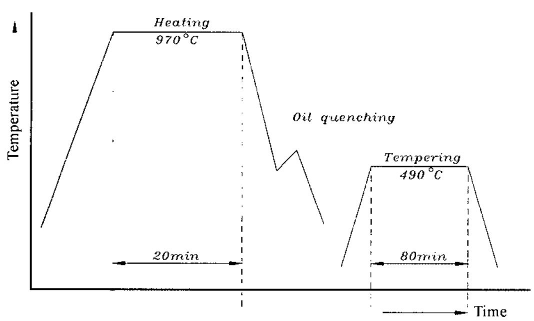


Figure 2. Condition of heat-treatment.

Table 2. Mechanical properties of SUP-9 steels after heat treatment.

Materials	Tensile strength (Mpa)	Hardness (HRc)		Elongation (%)
		After quenching	After tempering	
SUP-9 (Non)	980	–	–	9
SUP-9 (heat)	1350	57	44	9.4

Table 3. Conditions of shot peening.

Impeller diameter (mm)	Shot velocity (rpm)	Shot ball diameter (mm)	Arc height (mm)	Coverage (%)
490	2200	0.8	0.375	85

2.2. Shot Peening

To apply residual compress stress to the test piece, one stage shot peening was applied to the SUP-9 steel by using a shot peening machine used for the manufacture of leaf springs. The shot peening was applied to both sides to process evenly throughout the surface of the test piece. The shot peening was completed under the conditions shown in Table 3 (Park and Jung, 2003).

2.3. Experimental Apparatus

The methods to measure the corrosion rate each have their own advantages. This experiment, therefore, has adopted both methods at the same time that is to say, one, the weight loss method, can decide the corrosion rate by conventional methods, while the other, Potentiodynamic polarization, has been widely used because corrosion rates can be decided in a short time to be semi-continuous.

2.3.1. Corrosion solution

A 3.5% NaCl solution (pH 8) without deaeration was used to measure the corrosion potential as well as the corrosion current one time every 24 hours. It was replaced every seven days, and three test periods were used that is to say, time periods of 7-days, 14-days and 30-days were used. After the test, weight reduction was measured.

2.3.2. Experimental method

To remove superficial unevenness and for anodizing prior

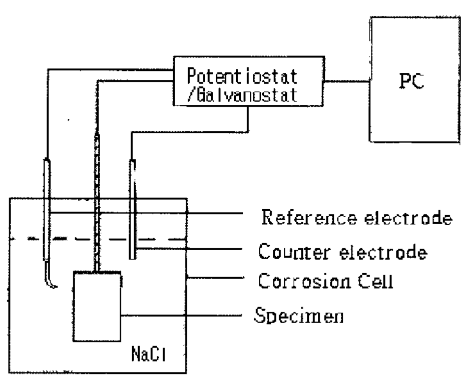


Figure 3. Schematic diagram of polarization test equipment.

Table 4. Measuring condition of residual stress.

X-Ray diffraction	Condition	
X-ray source	Target	Cr-V
	Voltage	30 kV
	Current	10 mA
Ø	0°, 15°, 30°, 45°,	
2θ	140°~170°	
Diffraction	Scintillation counter	

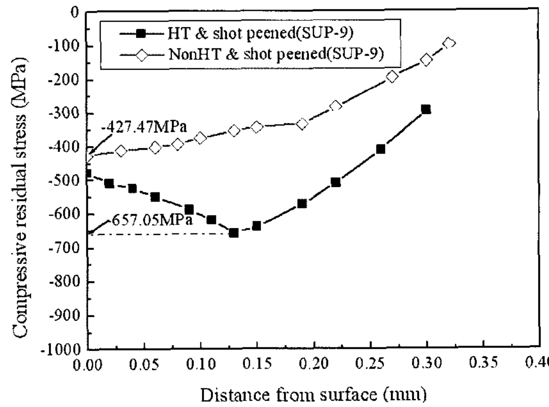


Figure 4. Compressive residual stress distributions of shot peened SUP-9 steel before immersion test.

Table 5. Compressive residual stress change through the immersion test.

		NOT-HT & shot peened	HT & shot peened
Compressive residual stress	Before immersion test	427.47 MPa	657.05 MPa
	After immersion test	320.00 MPa	630.00 MPa
	Loss	107.47 MPa	27.05 MPa
Flaking amount		0.012 mm	0.011 mm

to testing, the surfaces of four kinds of test pieces were polished using #100~2000 emery paper and then fat was removed using acetone. To protect an area from corrosion during the immersion test, an effective exposure area of 50×60 mm was insulated with silicon resin.

After polishing 10×10 mm of the effective exposure area, the fat was removed from the test piece with acetone to connect the polarization test equipment (Figure 3). The corrosion software measured polarization by using a EG&G273A Potentiostat/Galvanostat as along with personal computers.

The EG&G273A Potentiostat/Galvanostat has adopted a saturated calomel electrode (SCE) as a reference electrode and two high density carbon rods as a counter electrode, and the scan rate was 0.167 mV/sec. After the immersion test, unevenness of the surface was tested with KOSAKA, srfacorder SEF-30D. The test needle has a 2 μm radius at the end, 1 g weight, 1000 times longitudinal magnification, and 50 times horizontal magnification to investigate surface roughness. An X-ray residual compression stress tester (RIGAKN-MASF2M) measured the distribution of residual compression stress of the surface of test piece produced by shot-peening.

The electro polisher measured residual stress by polishing the test piece at the unit of 10~20 μm. The residual stress was tested with 2θ-$\sin 2\phi$ (ASTM, 1994) and its test conditions are shown in Table 4.

3. RESULTS AND DISCUSSION

3.1. Variation of Compressive Residual Stress due to Corrosion

Figure 4 shows the test results of compression residual stress of not only the Non-H & shot peened test piece of SUP-9 steel prior to the immersion test but also the HT & shot peened test piece. In the test result, the shot-peened test piece with heat treatment had 229.58 MPa (about 1.54 times) residual compression stress higher than the test piece without the heat treatment. This is because the heat treatment could soften construction of the surface to elevate plastic deformation. Therefore, bigger residual compression stress was made at the collision of shot ball.

Figure 5 shows the residual compression stress after the 30-days immersion test in the 3.5% NaCl solution. The test piece after shot peening without the heat treatment had 320 MPa of max. residual compression stress at 0.012 mm on the inner side of the test piece

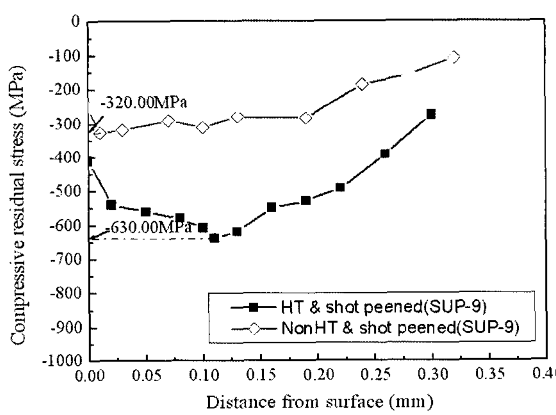


Figure 5. Compressive residual stress distributions of shot peened SUP-9 steel after the during 30 days immersion test.

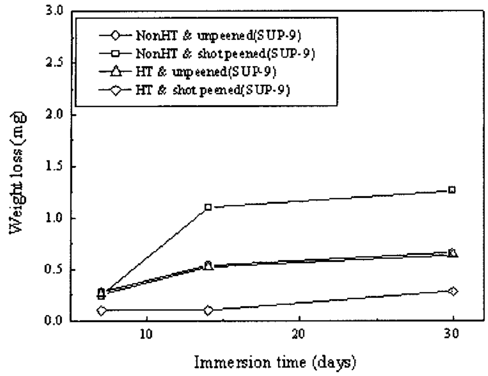


Figure 6. Weight loss versus immersion time of specimens immersed in 3.5% NaCl.

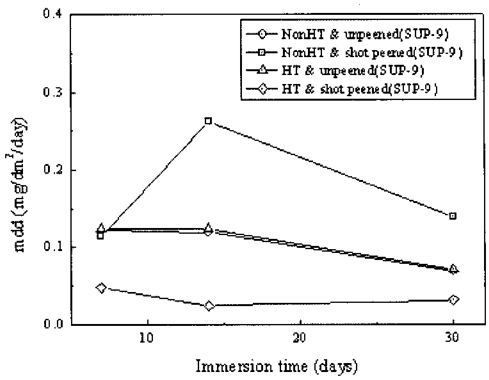


Figure 7. Corrosion rate, mdd versus immersion time of specimens immersed in 3.5% NaCl.

surface, while the one after shot peening with heat treatment had 630 MPa of max. residual compression stress at 0.115 mm on the inner side of the test piece surface.

Table 5 shows the residual compression stress and flaking amount before and after corrosion of both test pieces. The residual compression stress decreased because the growth stress at the production of the coating decreased from interaction with existing residual compression stress.

3.2. Variation of Weight Reduction and Surface Roughness after Immersion Test

Figure 6 indicates weight reduction after immersion for 7, 14 and 30 days. The weight reduction was measured before the test and after removing scale, slime and others completely to calculate the weight change.

The test result was as follows: When heat treatment was not added before shot peening, the weight loss of the shot peened test piece was bigger than that of unpeened test piece. This was because the compressive layer from the shot ball impact was discontinuous to make rough unevenness and accelerated corrosion. When a heat treatment process was added, continuously distributed residual compression stress increased to reduce sensitivity to corrosion.

Figure 7 shows the weight reduction shown in Figure 6 in mdd (mg//day) of corrosion rate. The test piece after shot peening without heat treatment rapidly increased for the first 7 days to be close to the unpeened test piece in accordance with time elapse. On the other hand, the test piece after shot peening with heat treatment had an almost constant value and increase little for 14 to 30 days. This is because the shot peening layer was dissolved in accordance with time elapse to be sensitive to corrosion at the inner side. Figure 8 has shown surface roughness by measuring surface unevenness.

Seven days and thirty days of immersion of four kinds of test pieces was tested and, surface roughness was measured by using KOSAKA, sufacorder SEF-30D. In general, surface roughness without the heat treatment was higher than the sample with the heat treatment. In other words, the test piece after shot peening without heat treatment became rough about 1.3 times, that is to say, from 4.82 μm to 6.27 μm, while the one after shot peening with heat treatment became rough 1.01 times, that is to say, from 3.80 μm to 3.83 μm. And, the maximum surface roughness (Rv) of the shot peening test piece without heat treatment increased by about 10 μm, while that of the test piece with heat treatment decreased by about 1 μm.

The test piece after shot peening without heat treatment had much weight reduction from corrosion. Therefore, heat treatment and shot peening is thought to have a great influence upon residual compression stress as well as corrosion resistance.

3.3. Variation of Corrosion Potential and Corrosion Current

Figure 9 shows the potentiodynamic test on the four kinds of test pieces to indicate Ecorr and Icorr by using the Tafel extrapolation method (Fontana, 1986). Table 6 shows the corrosion potential as the corrosion current of each test piece: all of the other test pieces other than unpeened without heat treatment sample had almost same values at the initial stage, while the unpeened test pieces without heat treatment had rather unstable values to be passive.

The unpeened test piece had a high corrosion current at high potential. The 3.5% NaCl solution destroyed the passive status from the influence of the Cl ion or increased current by direct reaction (see formula 1) (Jones, 1995).

$$Fe^{2+} + 2H_2O + 2Cl^- \rightarrow Fe(OH)_2 + 2HCl^- \quad (1)$$

Figure 10 shows corrosion potential every 24 hours

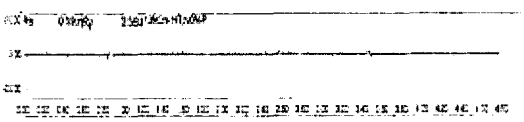
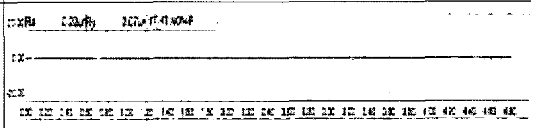
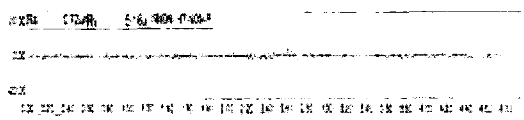
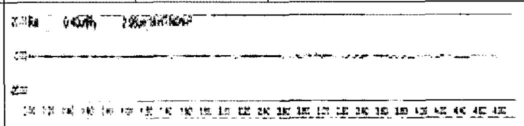
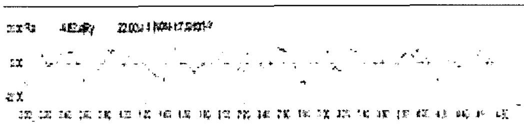
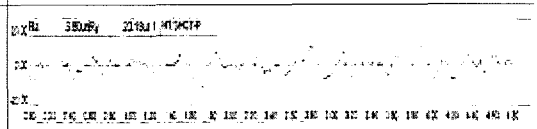
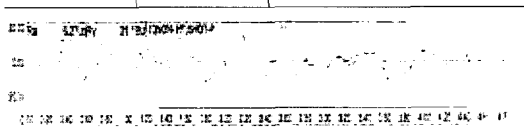
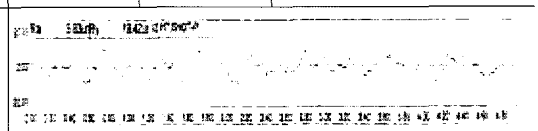
Non-HT & unpeened			HT & unpeened		
					
7days	Ra	0.39μm	7days	Ra	0.23μm
	Ry	3.56μm		Ry	2.07μm
					
30days	Ra	0.72μm	30days	Ra	0.40μm
	Ry	5.18μm		Ry	2.96μm
Non-HT & shot-peened			HT & shot-peened		
					
7days	Ra	4.82μm	7days	Ra	3.80μm
	Ry	22.00μm		Ry	20.18μm
					
30days	Ra	6.27μm	30days	Ra	3.83μm
	Ry	31.18μm		Ry	19.42μm

Figure 8. Surface roughness of specimens immersed during 7, 30 days in 3.5% NaCl.

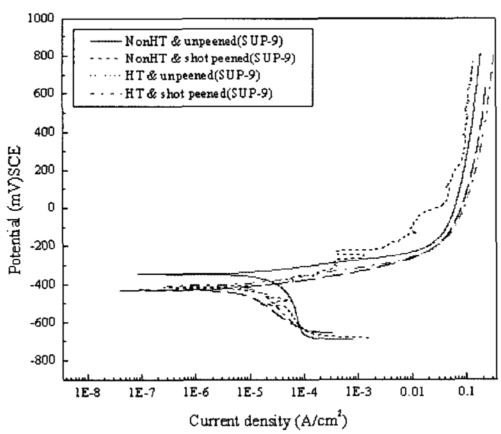


Figure 9. Polarization curves of specimens.

after 30-days of immersion in a 3.5% NaCl solution without degassing. The unpeened test piece largely showed (–) potential, while the shot peening test piece showed (+) potential rather than spontaneous polarization

Table 6. Corrosive potential and corrosive current of specimens through Tafel extrapolation.

	Ecorr (mV/SCE)	Icorr (A/cm^2)
Non-HT & unpeened	–340	4.2×10^{-5}
HT & unpeened	–410	2.7×10^{-5}
Non-HT & shot-peened	–420	8×10^{-6}
HT & shot-peened	–400	1.3×10^{-5}

(Jones, 1995; Lim and Yun, 2001; Lim and Han, 2000; Gibson, 1987).

The corrosion potential increased or decreased because of the increase in Cl ions in anodizing. And, after heat treatment, the shot peening test piece made (+) potential in accordance with the time elapse to change slowly. This is because the shot peening elevated resistance against a protective layer and corrosion fatigue cracking.

The shot peening looked to have an influence upon

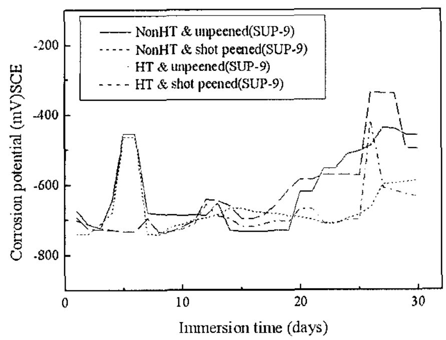


Figure 10. Corrosion potential versus immersion time of specimens as immersed in 3.5% NaCl.

residual compression stress, and heat treatment was added to the shot peening to increase residual compression stress and to elevate corrosion resistance.

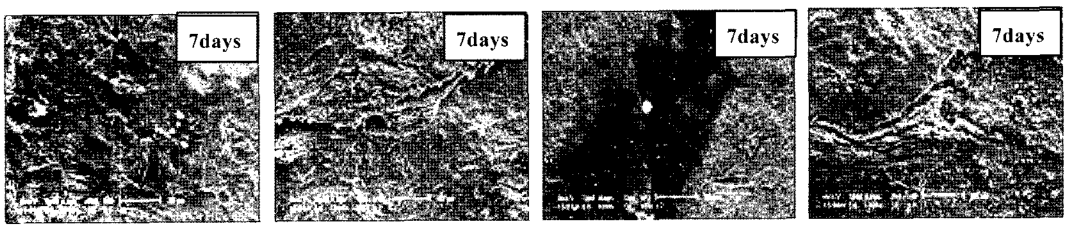
3.4. Characteristic of Fractured Surface

Figure 11 to 13 show photographs of the corrosion surface by SEM photographing (X1000 times) after 7-days, 14-days and 30-days immersion tests. All of the test pieces produced a lump-shaped corrosion pit under the influence of high carbon, and the shot peening test piece had an uneven surface because of the collision of the shot ball at the initial stage to produce a larger corrosion pit (Wraglen, 1972) than the unpeened test piece. The shot peening test piece with heat treatment produced a lot of corrosion pits because of the uneven surface in accordance with the elapsed time and the corrosion pit grew up to worsen corrosion because of Cl ion and oxygen accelerated the corrosion (Greene, 1961) compared to the unpeened test piece.

4. CONCLUSIONS

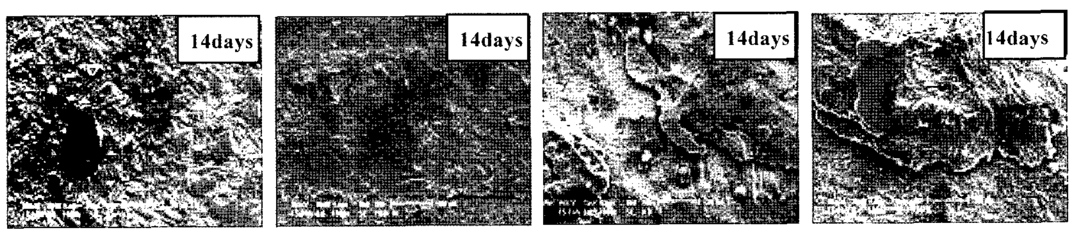
The study tested corrosion features in accordance with unpeened and shot peened spring steel and with the addition of a heat treatment process. The findings are as follows:

(1) The shot peening with heat treatment relieved surface



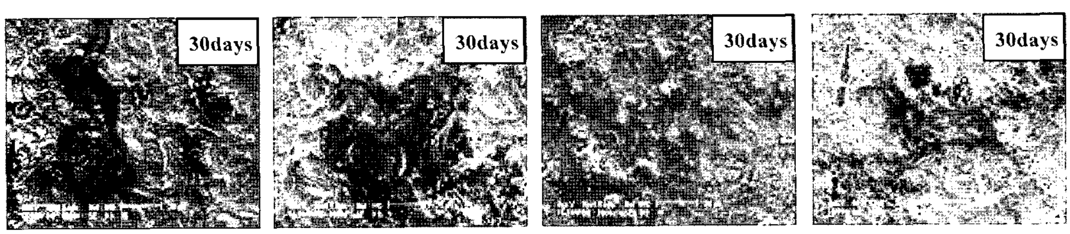
(a) NonHT & unpeened (b) NonHT & peened (c) HT & unpeened (d) HT & peened

Figure 11. SEM photographs of corroded surface after 7 days.



(a) NonHT & unpeened (b) NonHT & peened (c) HT & unpeened (d) HT & peened

Figure 12. SEM photographs of corroded surface after 14 days.



(a) NonHT & unpeened (b) NonHT & peened (c) HT & unpeened (d) HT & peened

Figure 13. SEM photographs of corroded surface after 30 days.

construction to elevate plastic deformation and to have higher residual compression stress.

(2) The shot peening material had a rough surface than the unpeened material. The shot peening test piece without the heat treatment had the roughest surface resulting in a high weight reduction and corrosion rate.

(3) The unpeened material had more corrosion potential at active (–) side than the shot peening material and had higher corrosion current than the shot peening material. This is because the shot peening raised resistance against corrosion fatigue cracking to improve corrosion features.
The shot peening material had inactive potential compared to the shot unpeening material and the shot peening material added heat treatment process to change the width of slow corrosion potential.

(4) When taking pictures of the corrosion surface by SEM after the immersion tests, the unpeened material produced more corrosion pits in accordance with the time elapsed than the peening material so that surface corrosion increased. And, the test piece without heat treatment produced more corrosion pit to increase surface corrosion than the unpeening material did.

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