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Impact resistance of steel partially prevented from liquid nitriding by inorganic coating

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The purpose of this paper is to investigate the effectiveness of an inorganic coating to prevent partial embrittlement or decrease in impact resistance. Charpy impact tests have been carried out, with the use of preventively coated specimens from liquid nitriding for various treatment times. The impact value and the fracture surface are discussed by comparing them with both nitrided and non-nitrided specimens. The results show that this method may be used as practical technique for partial prevention of liquid nitriding.

1. Introduction

Liquid nitriding is widely applied to improve the wear resistance and the fatigue resistance of machine parts [1–3]. However, the impact resistance is conversely reduced in spite of the improvement of those characteristics. Therefore, if the treatment is applied to the whole surface of the machine part, a portion of minimum cross section would often be fractured because of embrittlement. The reduction of the disadvantages of nitriding is strongly desired, but no practical method has yet been developed.

We have recently tried partial prevention of liquid nitriding by inorganic coating and investigated the various characteristics of the coated specimens. It was discovered that the mechanical properties of the coated specimen were retained to the same degree in the non-nitrided specimen [4, 5] and, furthermore, the fatigue resistance could be raised to a fairly high level [5]. However, previous studies have not clearly revealed the impact properties of the coated specimens. In this study, the impact resistance and the impact fracture surface of the specimen protected on notch portion are discussed by comparing them with both nitrided and non-nitrided specimens.

2. Experimental procedure

The materials used in this experiment were rolled bars of SAE 1015 steel. The specimens were machined from the central portion of bar steel and Fig. 1 shows the shape and dimension of the specimen. The shadowed portion in the figure indicates the portion to be protected by the inorganic coating. The composition of the coating is shown in Table I. The viscosity is ~ 70 Pa. The inorganic coating was hardened at 150° C for 60 min after being applied on the surface of the specimen from 200 to 300 μm thickness.

The preventively coated specimens (anti-nitride) and other specimens of the non-coated (nitride) were immersed in the salt bath at 570° C for periods from 5 to 180 min and afterwards cooled in water. The composition of the salt bath for nitriding is given in Table II. The impact tests were performed at 20° C by Charpy-type impact testing machine (294J).

TABLE I Chemical composition of an inorganic coating (wt %)

SiO_2	Crystalline	60	Aggregate
	Noncrystalline	10	
Na_2O		3	Binder
H_2O		27	

Viscosity: 70 Pa

3. Results and discussions

3.1. Microstructure

Fig. 2 shows the appearance of nitride and anti-nitride. The hardened coating in anti-nitride never produced removal and crack despite the sudden immersion in a 570° C alkaline molten salt, but was readily removed by water cooling after being removed from the salt. In Fig. 2, the trace of the protective coating in anti-nitride is observed. The formation of compound layer and diffusion layer are supposed to be less than that of the nitrided portion or nitride.

The X-ray diffraction patterns on the surface of nitride and anti-nitride are given in Fig. 3. The peak of ε-phase appears at 5 min and α–Fe is hardly diffracted at > 60 min in the case of nitride. On the contrary, in anti-nitride, α–Fe shows the peak at any nitriding time and the diffraction intensity of ε–Fe_2N tends to be low. However, the appearance of ε-phase in anti-nitride suggests the existence of a compound layer on the surface.

The microstructures of the section at notch root of nitride and anti-nitride were inspected, and are shown in Fig. 4. As is apparent in this figure, the compound and diffusion layers of nitride become thicker and deeper with the increase of nitriding time. The com-

TABLE II Chemical composition of salt bath (wt %)

KCN	KCNO	$Na_4Fe(CN)_6$
48.8	42.3	0.14

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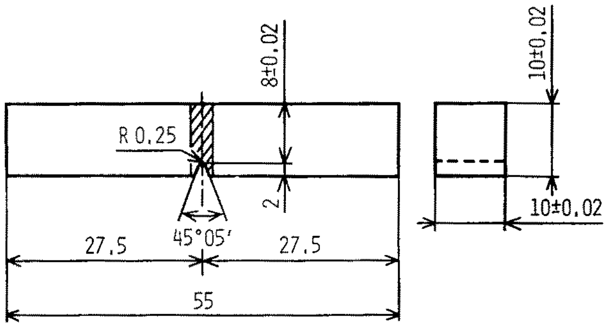

Figure 1 Test specimen (size in mm).

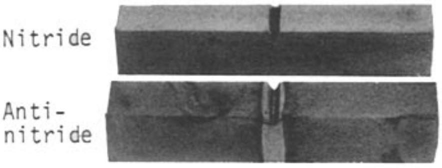

Figure 2 Appearances of specimens.

pound layer of anti-nitride had less correlation with treating time and moreover the degree was very much smaller than that of nitride and the precipitation of γ-Fe_4N was hardly found. However, it was difficult to prevent it completely, because the hardened coating had microscopic pores. The pores were considered to be formed by evaporation of H_2O from the hardened coating [4].

3.2. Impact resistance

Impact strength at room temperature in comparison with nitride and anti-nitride was examined. Fig. 5 shows the relation between Charpy impact value and nitriding time. The impact value of nitride dropped considerably at > 30 min and the average of five measurements was ~ 0.7 MJ/m^2 at 180 min. This value was only 29% that of non-nitride. That of anti-nitride dropped little, even though treating time was extended. The impact value was maintained at ~ 2.1 MJ/m^2 at 180 min and became three times that of nitride. However, the strength was reduced by $\sim 16\%$ and the cause of decrease could be attributed to the porosity of the hardened coating. It was clear that the impact resistance of the preventively coated specimen could be maintained at the same degree in the non-nitrided specimen, even if treating time were extended.

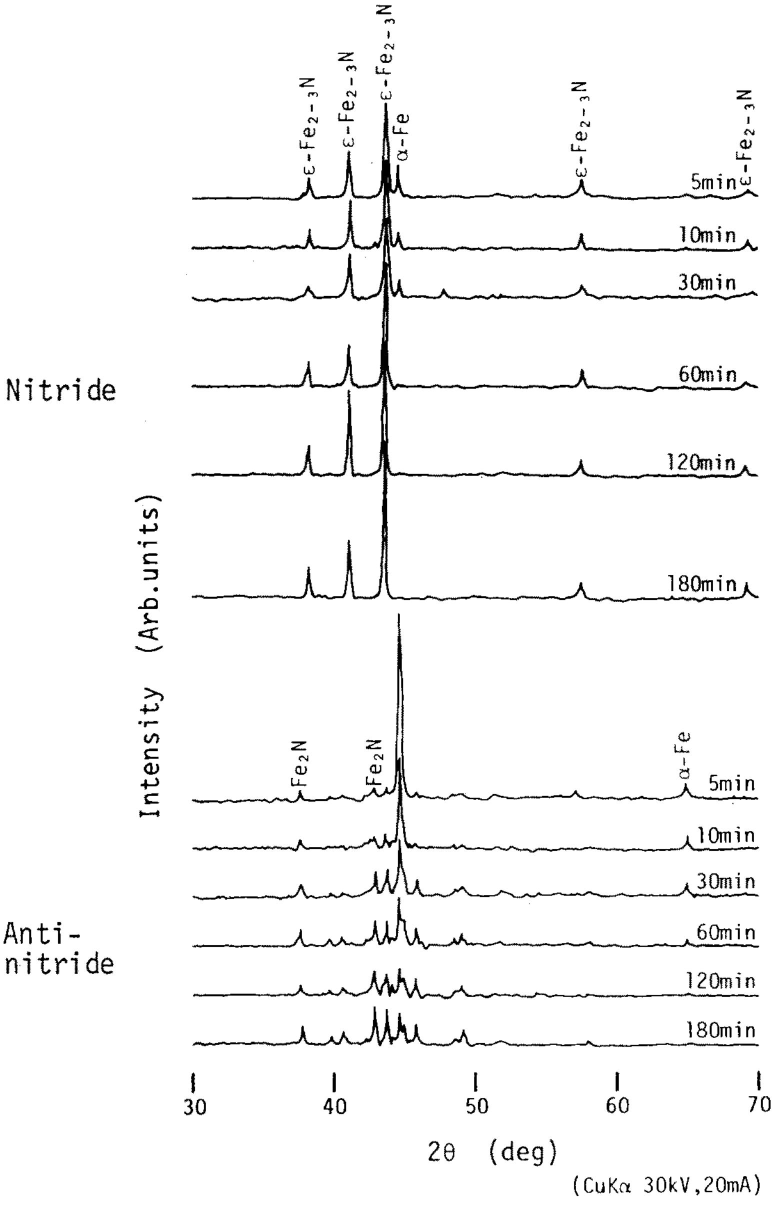

Figure 3 Diffraction intensity curves obtained by X-ray.

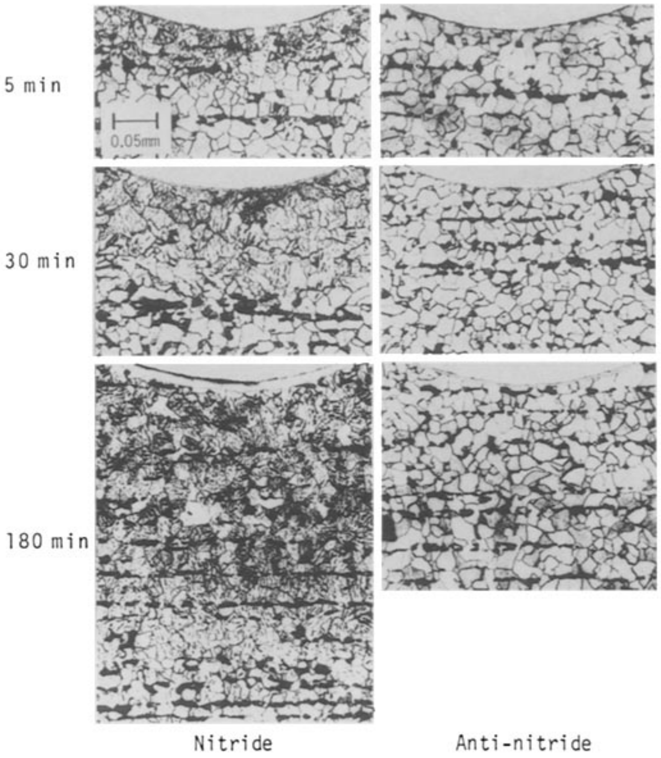

Figure 4 Microstructures in the vicinity of notch roots (tempered at 300° C for 60 min).

3.3. Impact fracture surface

Fig. 6 shows impact fracture surfaces of nitride and anti-nitride at each nitriding time. The shear lip appeared in a shorter time treating nitride, but at > 60 min the shear lip could not be found. The circumference portion of these nitride proved to be embrittled. In contrast to this, in anti-nitride the macroscopic fracture surfaces were hardly influenced by nitriding time and the brittle fracture was, almost in all cases, hard to procure.

Fig. 7 shows an example of fracture surface under SEM, at notch root, centre, hinge and lip, respectively. In Fig. 7, the SEM photomicrographs in non-nitride show the dimple pattern at any portion. But that of nitride at 180 min changed into a brittle fracture surface in the vicinity of the surface and the river pattern is recognized. On the contrary, in anti-nitride, it was difficult to detect the brittle fracture surface, even with a microscope and the fractographs were very similar to those of non-nitride at any portion.

These fractographic aspects are in good correspondence with the impact value in Fig. 5. In consequence, the impact resistance in anti-nitride was supposed to be maintaining a high level as a result of the restraint of compound and diffusion layer and also owing to the restraint on the increase of hardness of those layers.

4. Conclusions

Based on the results of the experiments, the following

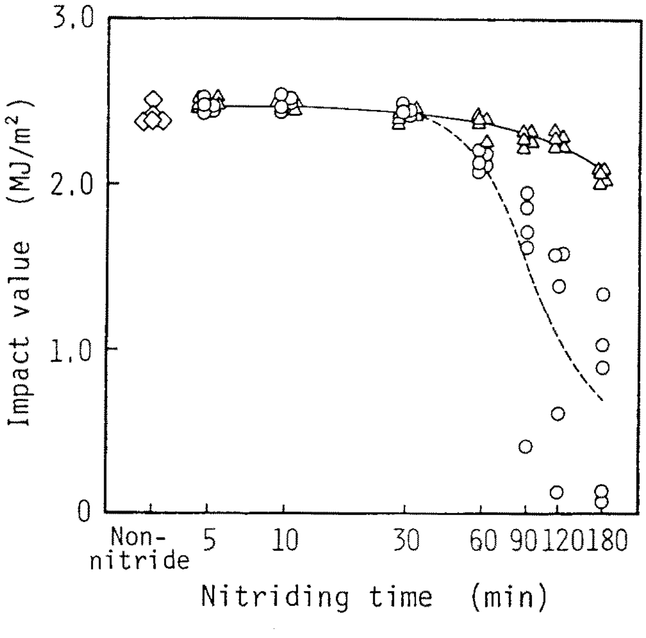

Figure 5 Relation between Charpy impact value and nitriding time (20° C). (- - ○ - -) nitride; (–△–) anti-nitride.

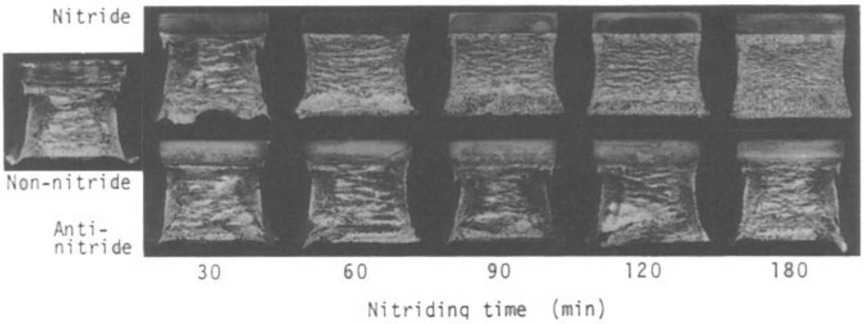

Figure 6 Macroscopic impact fracture surfaces (20° C).

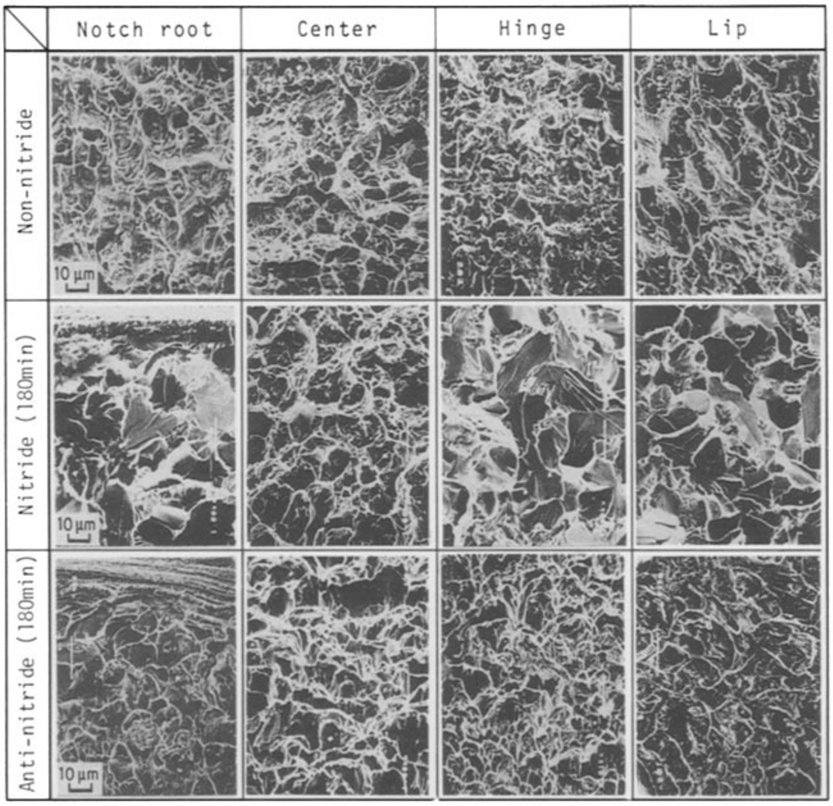

Figure 7 SEM photomicrographs of fracture surfaces.

conclusions may be drawn on the impact resistance of the specimens protectively coated with the inorganic hardened coating.

1. The impact resistance of the anti-nitrided specimen was reduced in accordance with nitriding time, but its degree was remarkably small when compared with the nitrided specimen.
2. The impact fracture surface of the anti-nitrided specimen showed the ductile fracture surface and was hardly influenced by nitriding time.
3. Although complete prevention was difficult, the inorganic coating could be applied most effectively to prevent partially the embrittlement and the decrease in impact resistance.

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