# Impact performance of electrodeposited nickel coating on steel substrate

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The nickel electrodeposited carbon steel sheet is a new type of material, it can be prepared by bilaterally electrodepositing nickel on low carbon steel sheet, then the coated sheet being heated by pulse laser thermal shock. It was found that this material has good corrosion-resistant, attractive toughness and excellent plasticity which offers the potential for advanced structure applications. So as to study this material's anti-impact performance, in the study, flat and tapered projectiles were used to impact the material in a 57 mm light air cannon, then the impacted specimens were inspected by scanning electronic microscopy. The surface and interface quality of the nickel coating was analyzed in detail.

A lower carbon steel sheet with thickness of 0.3 mm was used as substrate. A uniform nickel coating of thickness 3 $\mu$m was prepared by electrodepositing method on both sides of the steel sheet. The coating was obtained with nickel sulphate electrolyte which was composed of 250 g $NiSO_4 \cdot 6H_2O$, 50 g $NiCl_2 \cdot 6H_2O$, 35 g $H_3BO_3$ per liter. Pure nickel was used as the anode. Before electroplating, pretreatments were necessary to get rid of the impurities.

In order to modify the specimen and make the sheet in a good quality, a laser beam thermal shock was used to treat the specimens. In the investigation, the laser thermal shock processing was performed on a Nd:YAG laser (wave length $\lambda = 1.06$ $\mu$m) with adjustable frequency and single pulse energy. A computer-controlled X-Y translation stage was used to move the samples with respect to the stationary laser beam. The laser beam was focused by a columned lens and in a long ellipse shape acted on the specimen's surface. The laser parameters used in the experiment were given in Table I. As specimen was moved on the laser machine, the laser beam continually acted on it for thermal shock. The spot of it would overlap a little on the specimen to make sure that the thermal shock covers all area of the specimen's surface.

The chemical composition near the interface between the electrodeposited nickel coating and steel substrate was gradient. The residual stress in original electrodeposited nickel coating was tensile. Laser beam thermal shock could redistribute the residual stress in the nickel coating. It was found that the residual stress could be turned into compressive stress after laser treated [1].

Residual stress may affect the structure's function and properties of the coating, and the coating service life. Research has shown that residual compressive stress may cause delamination of coating from its substrate, whereas residual tensile stress may cause a surface crack in coating [2, 3]. So it is necessary to research the coating's performance on dynamic conditions that the residual stress may be severely acted.

In order to study the nickel coating's performance, flat and tapered projectiles were used to impact the specimens, with the projectiles pushed forward by compressive air in the light air cannon. After impact, the specimens were softly collected to prevent their followed deformation. In the experiment, the flat steel projectile weighed 448.7 g; tapered projectile had tapered angle 60$^\circ$, and its weight 700 g. All specimens had been cut to dimensions 105 × 105 mm. Before experiment, the specimen was glued to a frame, then the frame together with the specimen was installed on the 57 mm cannon barrel. The glue strength was very small compared to the projectile's impact intensity, its influence might be neglected especially in the place that the projectiles impacted. A electrical sensor was used to detect the projectile velocity, with a LeCro9370 1 GHz numerical oscillograph to capture the signal from the electrical sensor. The measuring error for the projectile velocity is not more than 2%.

Specimens were prepared under the same fabrication conditions of electrodeposition and laser thermal shock. Then they were impacted by projectiles at different conditions which were given in Table II.

For flat projectile impact, it was illustrated that the four specimens deformed permanently after impact, but the sheet did not rupture even at the maximal velocity of the flat projectile 61.7 m/s, which was shown in Fig. 1. On the deformed specimens the stamps produced by the

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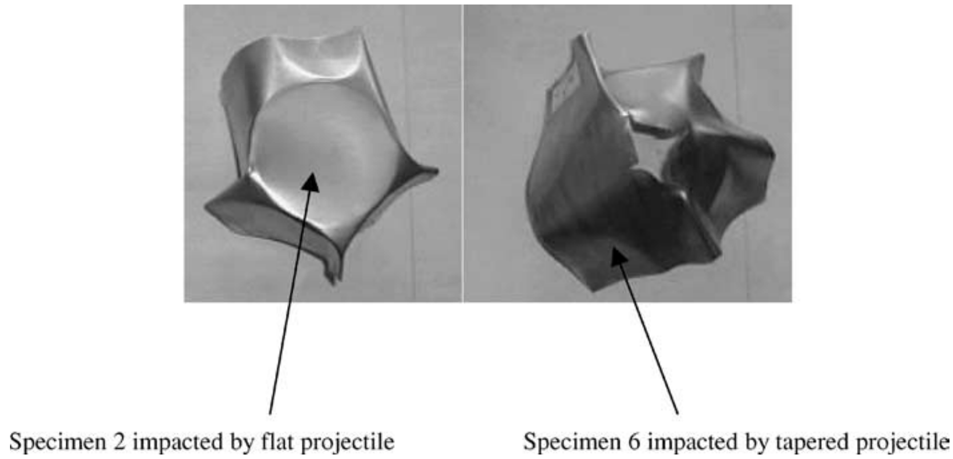


*Figure 1* Specimens impacted by flat and tapered projectiles.

edge of the flat projectile were very clear which could be seen by eyes.

For tapered projectile impact, it was showed that the four specimens entirely fractured after impact, even at the minimum velocity of 16.3 m/s. As the projectile was tapered, the specimens were split into 4 pieces at the impacted place, and the cracks were perpendicular to the edges of the specimens, which were demonstrated in Fig. 1. The cracks perpendicular to the edges of the specimen could be explained by dynamic wave transmission theory [4]. Since at the directions that were perpendicular to the edges of the specimens the time for impact wave to transmit was the shortest, and the material withstood the maximal tensile impact wave earliest, the original cracks would be appeared in these directions. As long as the material was uniform the cracks would be advanced keeping the directions.

The deformation and fracture of the coated sheet increased with the impacted velocity up, which could be seen from the shapes of the impacted specimens. At the beginning of the impact, the specimens loaded compressively. Due to the existence of free surfaces in the specimens and the inertia of the projectile, in the proceeding process the specimens were compressive in its thick direction, and tensile in its surface direction. Except that for tapered projectile, there existed stress concentration at the projectile impact area that contributed to the materials' fracture. For the impacted specimens the deformation and fracture were related to not only the strength and acting time of the impact wave but also the strength of the material and the quality of the nickel coating. Because there existed difference of mechanical property between the nickel coating and the steel substrate, if electrodepositing and laser thermal shock were not good and suitable, the nickel coating might be damaged and delaminated after impacted. Scanning electronic microscopy was used to check this aspect.

KYKY-2800 scanning electronic microscopy made in America was used to examine the specimens, for flat projectile impact to check the specimen's surface circumstance, for tapered projectile impact to examine the specimen's interface state.

For specimens 1, 2, and 3 as the kinetic energy of the flat projectile was not more than 407 Joule, they were not cracked after impacted from their surface morphologies. But for specimen 4, the flat projectile having great kinetic energy more than 731 Joule, the specimen's coating tended to crack after impact which was shown in Fig. 2. These tests demonstrated that the

TABLE I Thermal shock parameters of pulse laser beam

| Number | Power energy (J) | Frequency (Hz) | Duration (ms) | Scanning velocity (mm/s) |
|---|---|---|---|---|
| 1 | 13.1 | 1 | 4 | 1 |
| 2 | 4.2 | 20 | 1 | 0.5 |
| 3 | 2.4 | 20 | 1 | 1 |

TABLE II Conditions of specimens impacted by projectiles

| Projectile type | Specimen no. | Compressive air pressure (MPa) | Impact velocity (m/s) | Kinetic energy (J) |
|---|---|---|---|---|
| Flat projectile | 1 | 0.14 | 24.7 | 136.9 |
| | 2 | 0.3 | 38.0 | 324.0 |
| | 3 | 0.4 | 42.6 | 407.1 |
| | 4 | 0.54 | 57.1 | 731.5 |
| Tapered projectile | 5 | 0.2 | 25.8 | 233.0 |
| | 6 | 0.5 | 40.1 | 562.8 |
| | 7 | 0.8 | 56.9 | 1133.2 |
| | 8 | 0.1 | 16.3 | 93.0 |

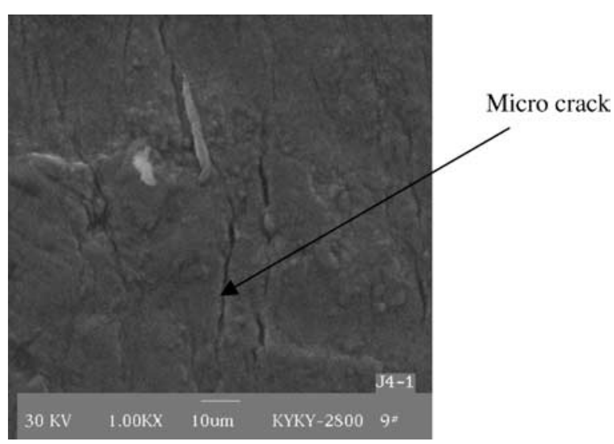


*Figure 2* Surface morphology of nickel coating impacted by flat projectile ($\times$1000, specimen 4).

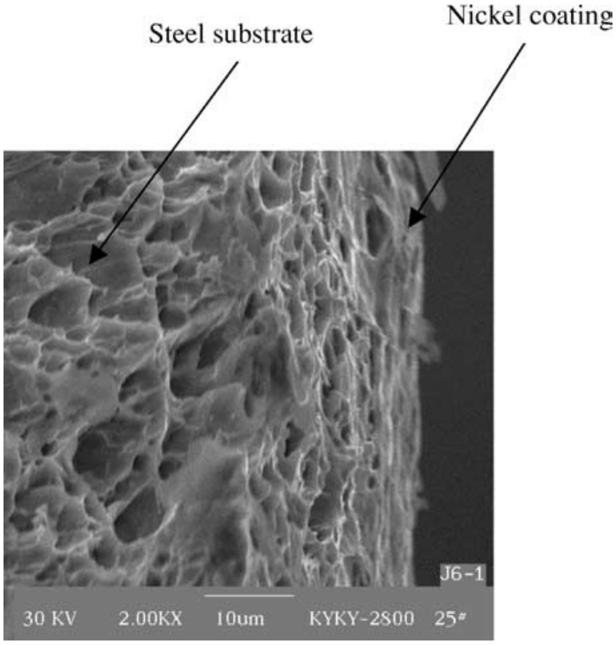


*Figure 3* Fractograph of nickel electrodeposited steel sheet impacted by tapered projectile (×2000, specimen 6).

nickel electrodeposited steel sheet had normal quality that it could withstand some extent of impact. If needed to withstand great impact nano-electrodeposit may be considered [5]. We also carefully examined the area near the stamps of the specimens in the scanning electronic microscopy, but no flaking found on their surfaces.

For tapered projectile impact, by carefully examining the fracture sections of the specimens 5, 6, 7, and 8 in the scanning electronic microscopy in both sides, we did not find any delamination. The fractograph for specimens 6 was shown in Fig. 3 could explain that. Some coatings were generally lower than their steel substrates, but we could see their fracture sections clearly in the microscopy by adjusting the heights and directions and the magnified times of the specimens. From these specimens' fractographs, it was found that the specimens' toughness concaves were deep, and the interfaces combined the nickel coatings with the steel substrates were not distinct but gradient, so the nickel electrodeposited steel sheet had high quality interfaces and excellent toughness. It could withstand impact of kinetic energy 1133 Joule and not to delaminate.

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