An explosive impact technique to nanocrystallize and harden surface of metal materials

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ABSTRACT

An explosive impact surface nanorisation technique (EISNT) was developed to prepare nanostructured surface layers on 45 medium carbon steel (MCS) and pure Copper (PC) plates. The plastic deformation involved the entire plate thickness of 6 mm, and sandwich structures were produced perpendicular to the impact direction. Nanocrystal layers with a thickness of about 50 μm were produced; the granularities were reduced to less than 20 nm for both metal plates. The surface microhardness was increased from 130HV to 475 HV for the MCS and from 70 HV to 160 HV for the PC respectively. An amorphous structure was formed in the surface layers. The cementite flakes within the pearlite appeared the slip, segmentation and fracture during the plastic deformation for the MCS. The nanostructure was ascribed to rapid cooling of the melted layer and the incomplete dynamic recrystallization for the MCS. In contrast, the nanocrystallization was mainly ascribed to the dislocation walls (DDWs) and dislocation tangles (DTs) in the PC.

Keywords: explosive impact; nanostructure; severe plastic deformation; surface; hardening

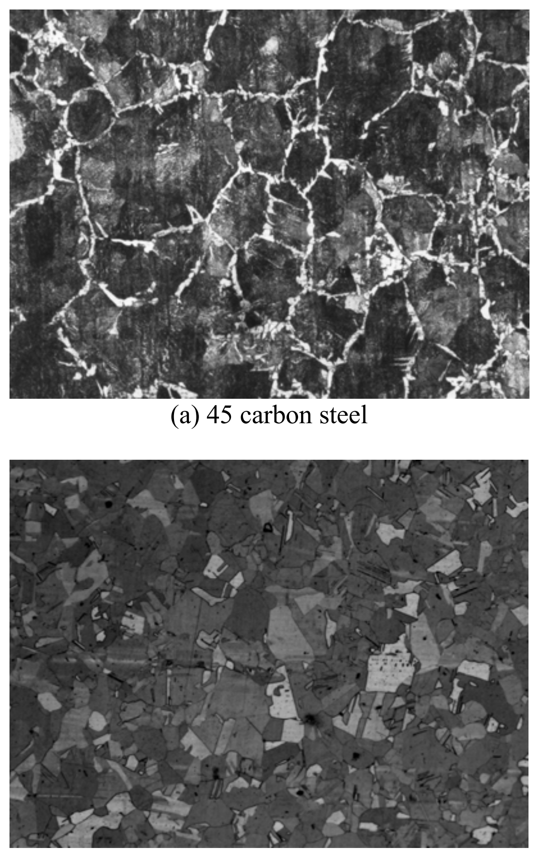
1 INTRODUCTION

Recently years, surface severe plastic deformation process has frequently been adopted to improve the hardness, wear resistance and fatigue lives for metals and alloys by introducing nanostructures into the surface layer of bulk metal materials, Base on this concept, many processes were developed, such as ultrasonic nanocrystal surface modification [1-2], supersonic fine particle bombardment [3-4], high-energy shot peening [5-6], surface mechanical attrition treatment [7-8], ultrasonic surface rolling processing [9-10], ultrasonic shot peening [11-12] and particle impact processing. On the other hand, explosive forming is a unique processing technique for surface hardening and welding composite of metal plates, which was recognized over 100 years, while the successful applications were seen in the early 1970s [13]. By the high-energy explosive impact, a severe plastic deformation can be induced in the surface, subsurface and even the entire body. This technique has special advantages, such as instant plastic deformation, large-surface processing, high degree of hardening and the formation of thick hardening layer.

With the increasing demand for high-hardness metal plates with large area in the field of transportation system, the surface hardening of the plates becomes more and more important in its application. Therefore, the present work aims to introduce the explosion impact surface nanorisation technique (EISNT) to treat medium carbon steel and pure Copper plates, and to investigate the effects of the explosion impact on the microstructure and properties of the metal plates. In the same time, the strengthening mechanism was investigated and compared each other.

2 EXPERIMENTAL PROCEDURES

The precursor materials were annealed 45 medium carbon steel and pure Copper plates, with a size of 500×150×6 mm Their microstructures are shown in Fig. 1.



(a) 45 carbon steel

(b) pure Copper

Figure 1: Microstructure of the samples

A steel anvilblock with a thichness of 10 cm was coated with a high-temperature lubricant, on which 4 support nails (φ2×3 mm) were placed. The steel plate or Copper plate was respectively installed on top of the nails horizontally. The emulsion explosive powders (explosive load of 1.97 g/cm^2) were uniformly paved on the plates, and the detonator was inserted. By igniting the detonator, the explosion was happened. The explosive surface experienced an impact of explosive heat airflow, and the impact surface experienced a strong impact with the rigid anvilblock. The initial impact speed of the plates can be calculated as approximately 460 m/s, which is much larger than those of the techniques above.

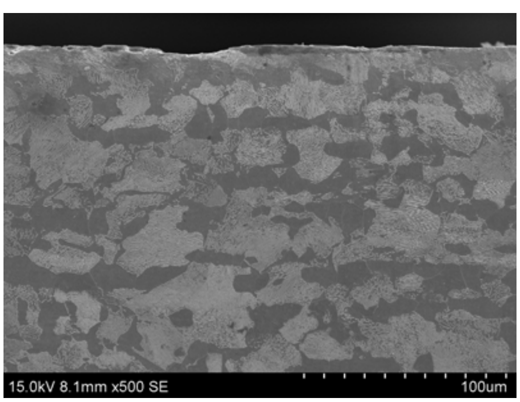
The microstructure of the samples was observed by a metallurgical microscope (GX51, OLYMPUS) and a scanning electron microscope (SEM) (S-3400, HITACHI). The surface layer of the treated samples was investigated by a high resolution transmission electron microscopy (HRTEM) (JEM-2010, NEC) and accessory selected area electron diffraction (SAED). The impact surface layer was examined by an X-ray diffractometer (XRD) (D/MAX-2500/PC, RIGAKU) .

The microhardness of the surfaces was inspected by a durometer (HXD-1000TM).

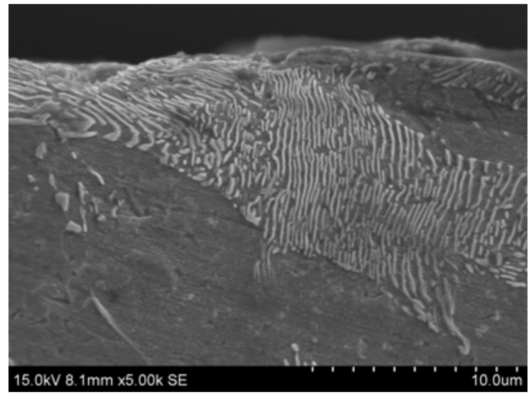
3 RESULTS AND DISCUSSION

3.1 45 steel plate

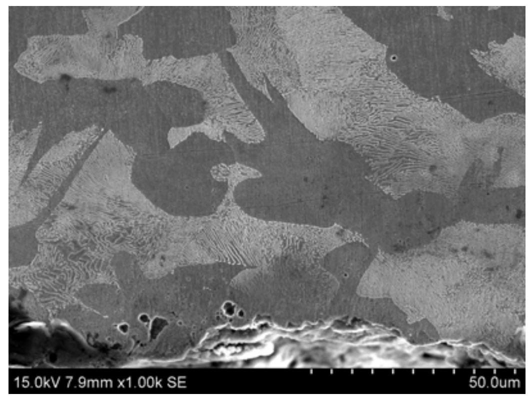
Figure 2 shows the microstructure on impact surface and explosive surface. Comparing with Figure 1a, it can be found that the morphology was greatly changed by the impact; the impact surface and explosive surface of the steel plate appeared a severe plastic deformation The ferrite phases were flattened along the direction perpendicular to the impact (Fig. 2a). Moreover, the fracture and segmentation of pearlite and a slip between the cementite flakes within the pearlite phases occured, as indicated in Fig. 2b and 2c. This phenomenon was not found in the SPD processes mentioned above. This is because that, a mall energy of impact was applied in the SPD processes, which can not promote deep plastic deformation. So the deformed depth is very limited. In contrast, the explosive impact with a large energy triggered a plastic deformation throioghout the plate depth, therefore, the microstructure was strongly compressed.



(a) sandwich structure near the impacted surface



(b) invaded pearlite from the impacted surface



(c) cracked pearlite near the explosive surface

Figure 2: Microstructure near impact surface and explosive surface

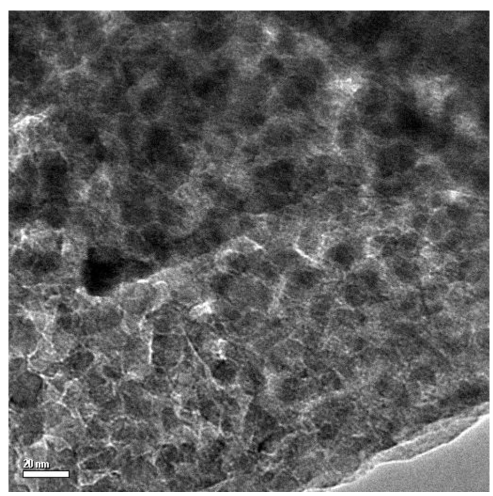


Figure 3: Nanocrystals of ferrite on impacted surface

Figure 3 shows nanocrystals of ferrite on the impacted surface. The nanocrystals were formed within the deformed ferrite grains, the size of which is less than 20 nm. However, the crystal type maintains ferrite crystal, which can be confirmed by the XRD measurement (Fig.4). Only the ferrite phase was identified (PDF 03-065-4899). The grain size can be calculated to be about 15 nm, which is roughly agree with the TEM result.

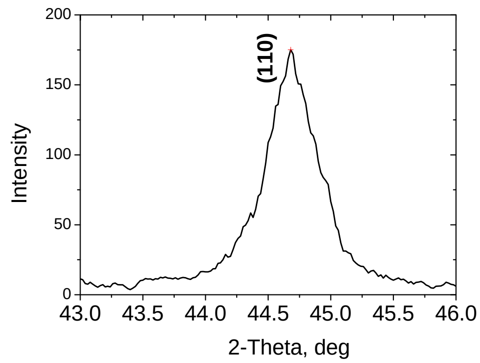


Figure 4: XRD pattern of ferrite nanocrystals on impacted surface

Moreover, the dense dislocation walls (DDWs) and dislocation tangles (DTs) were not found, unlike those reported in the literature [1, 2, 5]. This indicates that the MCS has a very different deformation mechanism from the SPD processes.

An amorphous structure companying the nanocrystals was confirmed by the SAED analysis as shown in Fig. 5, because of the incomplete diffraction rings This indicates thar, during the ecplosive and impact process, the surface was partialy melted and it has entirely not be transformed into crystals due to a very fast cooling rate. The nanocrystals can be partialy crystallized from the melts without a sufficient growth.

Fig. 6 shows the variation of microhardness of annealed and impacted samples along the depth direction. The annealed plate has an unchangeable hardness of about 130HV. Explosion impact enhanced the overall hardness, and the hardness on the impacted surfaces was enhanced to 475HV. Moreover, the hardness gradually decreased as the depth increases from the surface. The serve plastic deformation depth was about 500 μm. By inspecting the change of the microstructure, it can be estimated that the nanolayer depth was less than 50 μm. The increase of hardness is mainly ascribed to the surface nanocrystallization.

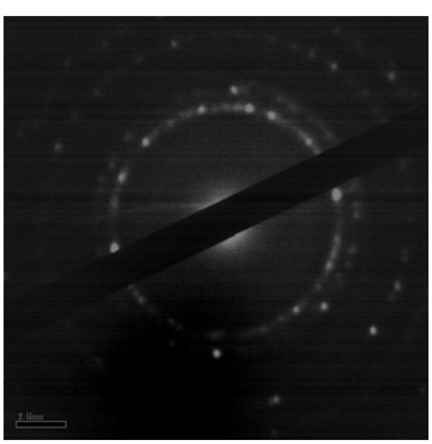


Figure 5: SAED pattern on the impact surface

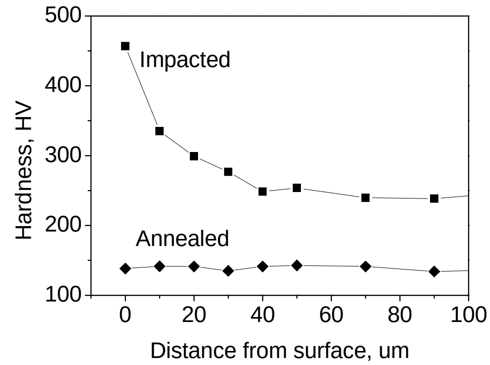


Figure 6: Microhardness of impacted and annealed samples

3.2 Pure Copper plate

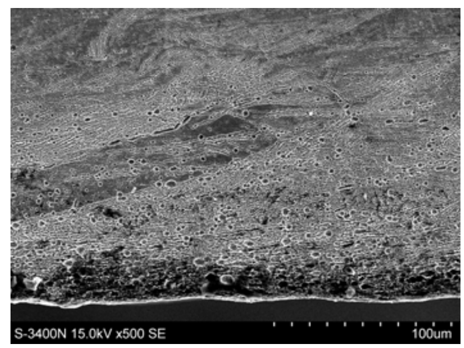


Figure 7: Microstructure near impact surface

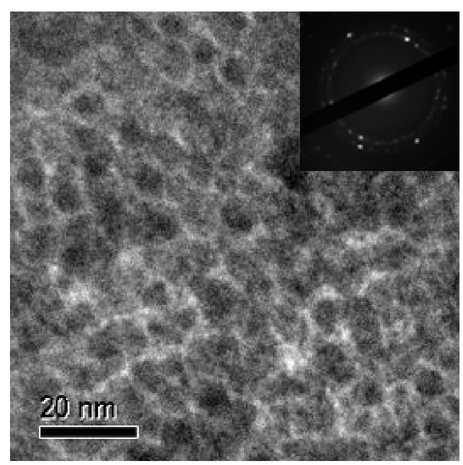


Figure 8: Nanocrystals on impacted surface

Aa the same as the 45 steel plate, the impacted Copper surface also appeared a severe plastic deformation. The grains were flattened along the direction perpendicular to the impact (Fig. 7) and the nanocrystals with a granularity of about 10 nm were produced on the surface (Fig 8). The XRD measurement confirms the granularity is about 12 nm (Fig. 9). From the SAED pattern in Fig. 8, it was observed that the diffraction rings were not with integrity, indicating an amoyphous structure coexisted. Moreover, the dense dislocation walls (DDWs) and dislocation tangles (DTs)

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were found on the impacted surface as shown in Fig. 10. Therfore, the nanocrystal were mainly formed by the dislocation behaviors.

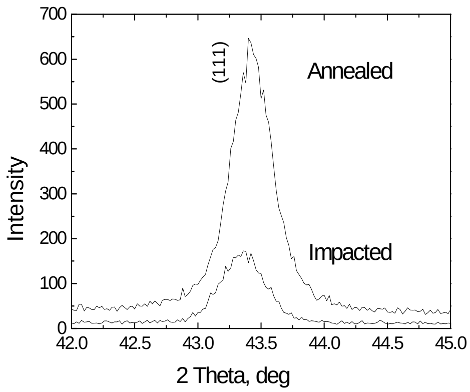

Figure 9: XRD pattern of impacted surface

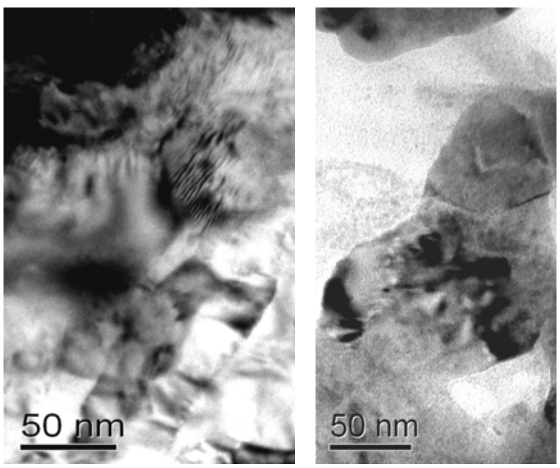

Figure 10: Dislocations on the impacted surface

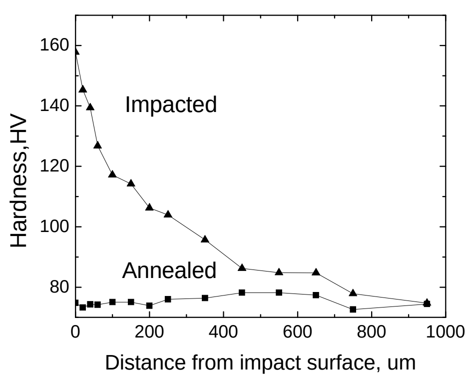

Figure 11: Microhardness of impacted and annealed samples

As regards to the difference in nanocrystal forming for MCS and CP, it can be concluded that the nanostructure was ascribed to the rapid cooling of the melted layer and an incomplete dynamic recrystallization for the MCS. In contrast, the nanocrystallization was ascribed to the dislocation walls (DDWs) and dislocation tangles (DTs) in the PC. The difference in the microstructure results in the different forming mechanism.

The microhardness of impacted surface was enhanced from 70 HV to 160 HV (Fig. 11), indicating a strong hardening effect.

4 CONCLUSIONS

The explosive impact produced lamellar structure, which was perpendicular to the impacting direction and a nanocrystal layer with a granularity of less than 20 nm appeared in the deformed grains was produced for 45 steel and Copper plates. The surface microhardness was increased from 130HV to 475 HV for the MCS and from 70 HV to 160 HV for the PC respectively.

The cementite flakes within the pearlite appeared the slip, segmentation and fracture during the plastic deformation for the MCS.

The nanostructure was ascribed to the rapid cooling of the melted layer and the incomplete dynamic recrystallization for the MCS; the nanocrystallization was mainly related to the dislocation walls (DDWs) and dislocation tangles (DTs) in the PC.

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