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Nanocrystallization of CK60 Commercial steel by Drilling Method

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Abstract: Drilling as a novel Surface Sever Plastic Deformation method (SSPD) has been applied to commercial CK60 steel plate to create a Nano Crystalline (NC) structured layer. In present study, the CK60 steel plate has been quenched in room temperature water from 950 °C (1 Hr) and tempered in 350°C for one hour. Drilling has been done with use of Ti-Carbide coated drilling bit under 10, 15 and 20 m/min speeds. The microstructure of the samples was studied by light microscope and high resolution SEM. The formation of NC layer having grain size in the order of 50nm was confirmed by the SEM observation and applying Hall-Pitch formula on the samples drilled with 15 m/min speed. The created fine grain zone is separated from base metal structure and clear boundary with 1 to 10 microns thickness where the drilling speed changes from 15 to 20 m/min. The microhardness test result illustrates that the hardness of surface NC layer increases almost more than twice when compared with coarse grain structure of base metal.

Key words: Nano Crystallinization, SSPD, Drilling, CK60 steel.

INTRODUCTION

Material scientist and engineers designed various type of special steels and ferro base high alloys in response to the increasing request of industry for steels with higher engineering properties. Alongside the engineer's attempts to design new steels, creating new techniques to modify steels micro structure, as an economical way to improve steels properties have also been vastly studied.

Nanostructured materials are polycrystalline materials with grain size less than 100 nm. Nano structure material exhibited improved novel mechanical, physical and chemical properties compared with their coarse-grained counterparts and attracted considerable scientific interests in the past decade. It has been shown that nano crystallization changes or improves material properties such as strength, hardness, wear resistance, corrosion resistances, electrical and magnetic properties. (C.Suryanarayana;C.C.Koch, 2000; Peng *et al*; 2006; Oliver *et al.,* 2009; Maoa *et al.,* 2010; Mao, *et al.,* 2010; Roland, 2006; Khodabakhshi, *et al.,* 2010) In general, NC material shows superior mechanical properties although some recent studies shows the contrary behaviour when the grain size goes under 20 nm.(Podrezov, 2006; Schuh *et al.,* 2002; Nieha, J.G.W., *Hall–Petch,* 2005; Suwas *et al.,* 2009; Malow, T. and C. Koch, 1998) Severe plastic deformation (SPD) methods to produce nanocrystalline materials are based on applying high strain in a short period of time to break grains and create fine structure. Various SPD techniques have been developed to fabricate NC materials, such as surface mechanical attrition (Malow, T. and C. Koch, 1998; Taoa, *et al.,* 2002), punching (Maoa *et al.,* 2010). sandblasting, ball milling (BM), high-pressure torsion and the equal channel angular press (Oliver, 2009), wire brushing(Masahide Satoa, 2004), sliding wear, roll bonding process (Shaarbaf and Toroghinejad, 2009) and shot peening (Minoru Umemoto, 2003; Sara Bagheri Fard, 2009).

There is a report regarding application of high speed drilling technique to create NC layer on Fe-C samples (Todaka *et al.*, 2005). Drilling as a simple, fast, easy controllable and low cost method could be effectively used in providing NC samples for further experiments and fundamental research studies. In this article, the drilling technique with low drilling speed has been successfully used to create fined grain nano layer on the CK 60 commercial steel.

2. *Experimental:*

Samples were cut in 2x2 cm from CK60 commercial steel Plate, 0.5 mm thick, with nominal chemical composition shown in table (1). All samples were austenitized at 950 °C for 1 hour and quenched into water with room temperature and tempered at 350°C for one hour in a muffle electrical furnace. The drilling was

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performed by using the titanium carbide coated bit with 5.0 mm in diameter. The cutting speed was 10, 15 and 20 m /min. Water soap was used as coolant during drilling.

The drilled plates were grinded by SiC emery paper, polished up to 0.2 µm and etched in 2% natal solution. The cross-sectional and microstructure features in the surface layer of the drilled hole were studied by High Resolution Scanning Electron Microscope (FE-SEM NOVA-NANO-SEM230). Hardness test performed on the hole fined grain (NC) surface layer, affected sub layer where the grain size has been slightly reduced and the base metal with Micro Vickers Hardness test. (Wolter-w-Group 401 MVD).

Table 1: CK60 Steel, Chemical composition (DIN. 17200)

Steel	Chemical composition wt%
CK60	0.61 C, Si Max 0.4, Mn 0.75, Mo max 0.1, Ni Max 0.4

The light microscope micrograph of quenched and tempered CK60 sample in Fig(1) shows martensite base structure with remaining austenite phase in grain boundaries. The average grain size of the base metal is determined 26 µm by metallographic method. (Average of 50 measurements)

The cross-sectional SEM observation of the drill holes top surface (Fig. 2 a and b) shows no significant change in grain size on the sample drilled under 10 m/min speed and the average grain size on the drilled hole edge is determined 17 µm. SEM micrograph of effected zone around drilling hole in Fig (3) showed a thin fine grain structured zone when drilling speed increases to 15 m/min. Study on the crystalline structure of this layer in higher magnification (24000X) shows that the grain size of this surface layer is in nano meter scale. The thickness of deformed or effected sub-layer is about 10 µm where the thickness of this fined NC layer is 1µm in average.

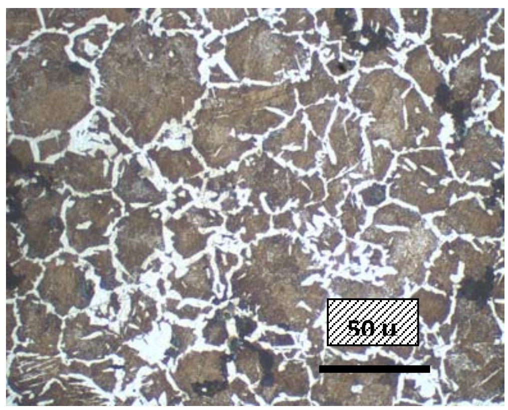

Fig. 1: The light microscope micrograph of quenched and tempered steel CK60, etched in 2% nital solution.

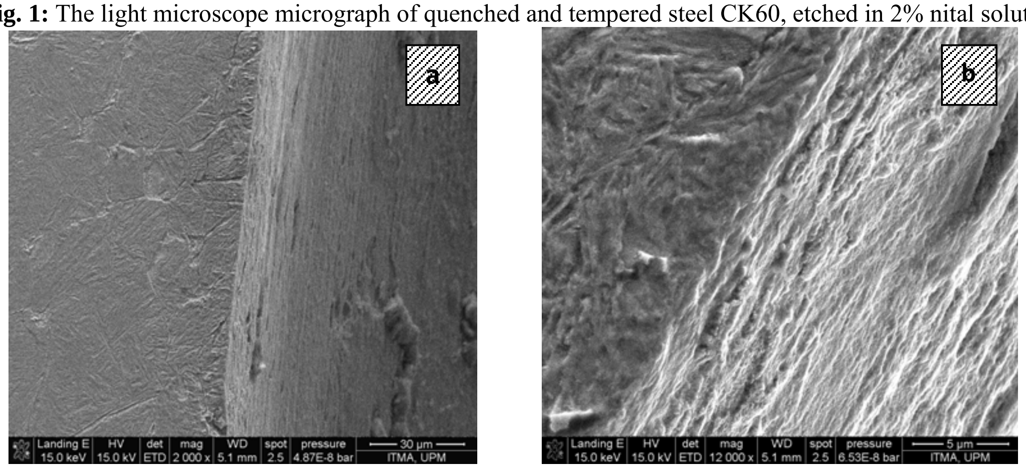

Fig. 2: A cross-sectional SEM observation of the CK60 steel drilled under 10 m/min. a) 2000X and b) 12000X

The same NC layer formed and observed in the sample drilled under 20 m/min speed (1275 rpm) in Fig (4). This NC layer with average 10 µm thickness has a clear boundary with affected sub-layer. The slipping trace with the deformation sharp angle of about 85˚ could be observed in Fig(5) and assuming that the 20 m/min is the minimum required drilling speed to create NC structure in CK60 steel, the amount of critical strain can be estimated in order of 11.

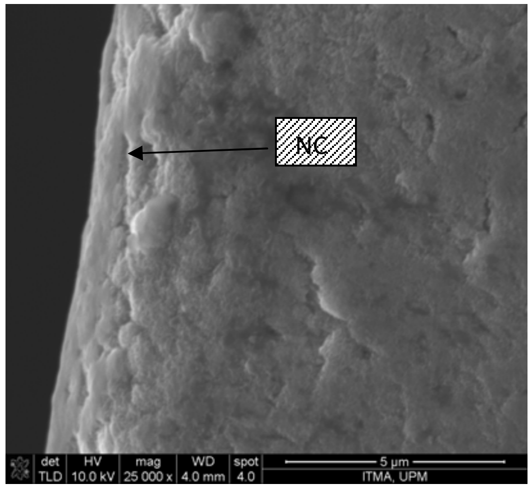

Fig. 3: The SEM Micrograph of CK60 steel drilled under 15 m/min speed.

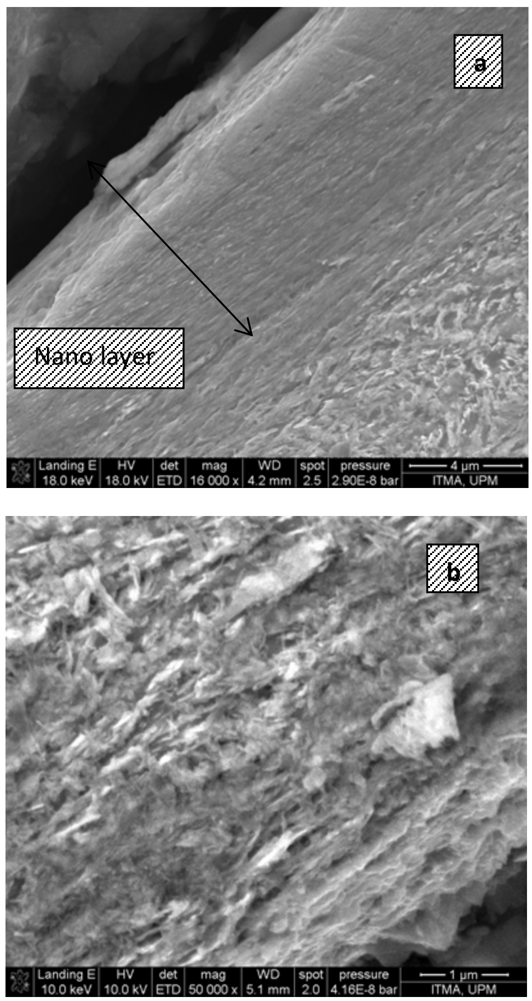

Fig. 4: The SEM Micrograph of CK60 steel drilled under 20 m/min speed. a)16000 X and b)50,000 X

Micro Vickers hardness test result on the CK60 sample driller under 20 m/min speed table (1) shows that micro hardness value increased more than twice in NC layer from 4.1 GPa in substrate to 9.8 GPa in fine structured surface layer, and slightly enhanced in affected deformed sub-layer.

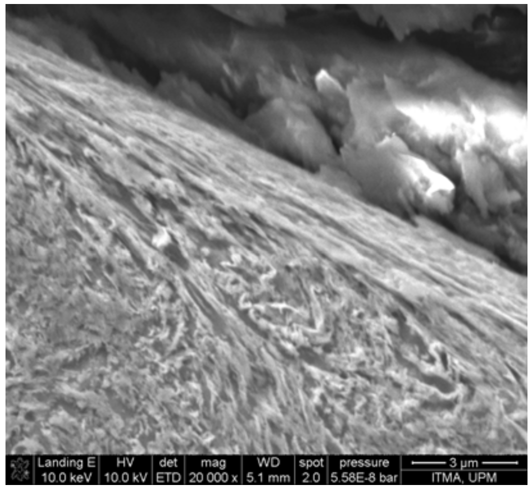

Fig. 5: The micrograph of sharp deformation angle – trace in sample drilled under 20 m/min speed.

Table 2: Microhardness test result for CK60 steel quenched 950 C (1Hr) and tempered 350 C (1 hr), drilled with 20 m/min speed.

Test Position	Average Micro Hardness(GPa)
Base Metal	(4.0,4.4,3.9) 4.1
Sub Layer	(5.1,4.6,5.0) 4.9
NC Layer	(10.5, 9.6, 9.3) 9.8

The hardness figures are the average of three measurements.

4. Discussion:

There are few reports about formation of NC layer on Fe-C samples by drilling severe surface plastic deformation technique in high cutting speed (Todaka *et al.,* 2005). The SEM micrograph studies in the present research (Figs 3 and 4) showed that that the surface NC structured layer forms on the CK60 commercial steel by drilling technique in low cutting speed of 15 m/min. As it has been already reported in other research studies, increasing the drilling speed and applied strain directly increases the NC layer thickness (Minoru Umemoto, 2003; Todaka, *et al.,* 2005) The thickness of NC layer has changed from 1 to 10 µm when the cutting speed increases from 15 to 20 m/min.

In Severe Plastic Deformation (SPD) methods like shot penning and drilling, increasing the dislocation's volume to a critical density produces new sub-boundaries and causes grain break-down to smaller grains. Formation of fined grain layer in lower drilling speed in this research can be attributed to the presence of almost high impurities, defects and dislocation density in commercial steels. Presence of these microstructure defects quicken the process to achieve critical dislocation density for producing new sub-boundaries, during drilling of the samples.

Reviewing previous related reports showed the amount of required strain for nanocrystallization in SPD methods on steels varies from 7 to 31 depending on the deformation rate and materials employed.(Minoru Umemoto, 2003) The amount of strain in the present study approximated 11 considering deformation angle on the battery limit of NC layer and sub-layer (Fig. 5).

The micro hardness test result (Table.2) showed that the hardness of surface fined grain layer is 9.8 GPa where it is 4.1 GPa in base metal. This hardness increase in the NC layer could be attributed to work hardening effect and grain size changes. Considering Hall-Pitch relationship the strength or Hardness of polycrystalline materials is expected to Increase with decreasing grain size, based on the classical Hall–Petch (H–P) relationship:

$$\delta = \delta 0 + K_{h.} d^{n}$$

where d is the grain size, δ flow stress, δ0 the lattice friction stress to move individual dislocations (or the Hardness of a single crystal specimen when $d \rightarrow \infty$), n the grain size exponent (normally is -1/2), and K_h is a constant, called H–P intensity parameter. (Minoru Umemoto, 2005; Nieh and Wang, 2005) if we postulate that measured 9.8 GPa hardness for NC layer is simply a result of grain size change and grain boundary strengthening, the grain size of NC layer could be calculated to be around 50 nm, assuming that the approximate relation between micro hardness and flow stress is Hv = 3 δ.

5. Conclusions:

1. In this study, drilling as a simple surface nanocrystallization process, successfully conducted on commercial steel CK60 and NC layer with grain size of about 50 nm formed on the surface of drilling

hole at 15 m/min drilling speed.

2. NC layer with thickness of 1 and 10 μm were created by low speed drilling of 15 and 20 m/min.
3. The required strain to create NC structure on CK60 steel is approximated 11.
4. The Micro hardness of NC layer is measured to the 9.8 GPa which it is more than twice the value of base metal hardness (4.1 GPa) in sample drilled with 20 m/min speed.

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