*Journal of Minerals and Materials Characterization and Engineering*, **2012, 11, 1034-1038**
Published Online October 2012 (http://www.SciRP.org/journal/jmmce)

# Investigation into the Deep Drawability of 0.1%C Eutectoid Steel

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Received June 10, 2012; revised July 18, 2012; accepted August 2, 2012

## ABSTRACT

The phenomenon of anisotropism in most rolled products necessitates that the rolling direction that enhances desirable mechanical property is established. In this paper, the comparative deep drawability of as-received and annealed mild steel containing about 0.1%C was investigated. The flat steel sample was divided into two and classified as as-received and heat treated respectively. The heat treated sample was obtained by annealing at 950˚C after been soaked for 5 hours and deep drawn at ambient temperatures (35˚C - 42˚C). From both samples, circular specimens were machine- blanked parallel to the rolling directions inclined at 0˚, 45˚ and 90˚ respectively and were prepared for deep drawability test while rectangular specimens were prepared for tensile test. Both specimens, as-received and annealed were then subjected to tensile, cupping and microstructural analyses. Results show that the contribution to increased formability at 90° rolling direction seems to have come from the spheroid-like pearlite grains induced during annealing while the stability of spread observed was achieved through a modest increase in strength. Thus, the resistance of annealed eutectoid steel to cupping is quite minimal at 90° to the rolling direction. The desirable drawability characteristics developed by the annealed eutectoid steel specimen are: cup-height, 30 mm maximum and ear, 6.4% maximum.

**Keywords:** Eutectoid Steel; Drawability; Annealing; Cupping; Anistropism

## 1. Introduction

The ease and extent of plastic deformation suffered by low carbon steel employed in the production of flat sheet profiles is a measure of its drawability. With minimal resistance to deformation, significant reduction in tool wear rate is often achieved. In recent years, a lot of research has been carried out on deep drawing of aluminum and steel alloys probably because they are amenable to heat treatment during plastic deformation. According to Miller *et al*. [1], deep drawing process finds application in numerous fields such as in automobile industries where the trend is towards safety and fuel economy. However, the stability of spread of an extensively drawn aluminum alloys is often a major concern. Hence, the application of high strength steels is connected with their characteristics improved spring back as a measure of spread stability during deformation. In most deep drawn components, adequate spring back is one of the means of ensuring accuracy of shape geometry [2].

Consequently, the role of grain size refinement in improving both strength and toughness in deep drawn materials has become imperative. Fine grained structures can be conventionally obtained by recrystallization during thermo mechanical treatment of steels. This has given rise to the development of various processing techniques leading to the refinement of ferrite grains for enhanced formability [3]. In this regard, the development of cold rolled steel sheets with very good drawability is indeed witnessing increased demand in the automotive industry. The research in this direction is towards producing steels with ultra low carbon comparable to interstitial free quality. It is established [4] that steel with very low carbon content produces better quality plastic deformation characteristics in drawing. However, this type of innovative process technique requires the use of vacuum degassing to improve formability, which is rather expensive. In contrast, decarburization heat treatment after cold reduction has proved to be an effective alternative. The technique makes use of process-gas ($N_2$ + $H_2$) atmospheres which when wet will react with the carbon in the steel while the carbon leaves as carbon monoxide (CO). The steel obtained have good grain size and desirable mechanical properties [5]. Similarly, through a novel thermo mechanical processing of low carbon steel having carbon in the range of 0.02 - 0.15 wt%C and phosphorous up to 0.28 wt%, [6] obtained tough and significantly ductile characteristics equivalent to high strength low alloy steels (HSLAs).

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The above new found technique presents clearly different conventional rolled product microstructure transformation regime. Normally in practice, after conventional hot rolling of mild steel, a lamellar pearlite is formed during austenite-ferrite transformation. The lamellar morphology of pearlite often leads to impaired mechanical properties which may render the steel unsuitable for further cold treatment. The globular morphology of cementite however, provides some benefits such as high toughness, good cold formability and machinability. According to Storojeva *et al*.[7], for such higher cold formability to occur, the strip must either undergo a long annealing treatment or it must be quenched with subsequent tempering for a good combination of strength and toughness. However, [8] achieved significant improvement in ductility and toughness in low carbon steel through the development of dual matrix structure by combining fast quenching from austenite phase followed by annealing in the intercritical temperature range of 710˚C - 790˚C.

As earlier suggested by Bello *et al*. [9], it is imperative that a method is developed for the measurement of the extent of plastic deformation suffered by steel undergoing various degree of microstructure evolution. Although the deep drawing process of high strength/low formability metals has an extensive industrial application, deep drawing at room temperature has serious difficulties because of the large amount of deformations required coupled with high flow stresses of the materials [10]. Thus crumples, wrin- kles and earrings invariably occur on the product surface because of the anisotropic property of the materials. At some elevated temperatures however, the flow stresses decrease giving rise to increased formability and thus, deformation becomes easier. The current study employs process annealing to simulate the formability response of eutectoid steel.

## 2. Methodology

The spectrochemical analysis result of the as-received flat steel sample used for this study is presented in **Table 1**. The steel sample was divided into as-received and heat treated (annealed) respectively. From the annealed sample, two types of specimens were prepared at ambient temperatures (35˚C - 42˚C).

These consist of circular blanks, 60 mm in diameter and 1.2 mm thickness for cupping test while rectangular blanks of 100 × 25 × 1.2 mm were machined for tensile test. Both types of specimens were then heat treated at 950˚C, soaked for 5 hours and furnace cooled.

In order to simulate the anisotropic characteristics of the material, the circular blanks specimens were cut at 0˚, 45˚ and 90˚ to the rolling direction and then deep drawn using an Erickson cupping machine. The minimum and maximum heights of cups formed were measured using a digital vernier caliper. The results of these measurements and computations with regard to cup ears and height in relation to their variation with angle of inclination to the rolling direction are illustrated in **Figures 1** and **2**.

Tensile test was carried out on both the as-received and annealed rectangular specimens in accordance with ASTM E8 using Monsanto tensometer at the rate of $10^{-3}$ s until fracture occurred. The ultimate tensile strengths exhibited by the specimens are shown in **Figure 3**.

Test pieces of as-received and annealed specimens for microstructural analyses were prepared by grounding in succession on 80, 240 and 360 grit emery papers and polished using alumina powder paste. The specimens mirror-like surfaces were then etched in Nital solution for 20 seconds and the microstructures viewed under an optical metallurgical microscope at a magnification of ×800. The photo micrographs are presented in **Plates 1** and **2**.

## 3. Results and Discussion

### 3.1. Tensile Strength Response of Test Specimens

Both the annealed and as-received specimens demonstrated decreasing ultimate tensile strengths as the angle of inclination to the rolling direction changes from 0˚-90˚ (**Figure 3**). This behaviour is attributable to the type of microstructure transformation that occurred, particularly in the annealed test specimens.

As observed in **Plate 1(a)**, coarse pearlite precipitates clustered around the ferrite-pearlite grain boundaries in the rolling direction. Though the clustering of coarse precipitates reduced considerably at 45˚ rolling direction, higher volume fraction of the precipitates remained in the matrix (**Plate 1(b)**). The ensued tensile strength variation (**Figure 3**) apparently can be associated with the Hall-Petch relation considering the apparent change in grain size. Further, the 450 - 550 MPa range of tensile strengths exhibited by the annealed test specimens indicate significant reduction in tensile strength compared with 750 - 787 MPa for the as-received specimen. This is due to the homogeneous dispersion of pearlite crystals within the matrices during annealing.

It is expected that such quantum decrease in strength, about 35% will translate to appreciable level of reduction

**Table 1. Composition of the steel sample.**

| Element | C | Si | Mn | P | S | Cu | Sn | Ni | Cr | Pb | Fe |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Composition (%) | 0.095 | 0.009 | 0.141 | 0.012 | 0.016 | 0.028 | 0.002 | 0.022 | 0.004 | 0.001 | 99.67 |

 

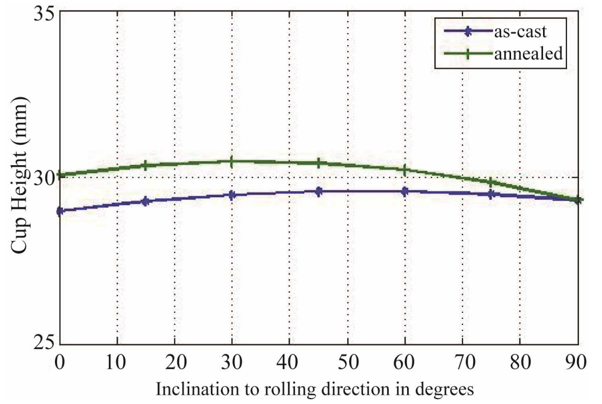


**Figure 1. Cup height against inclination to rolling direction.**

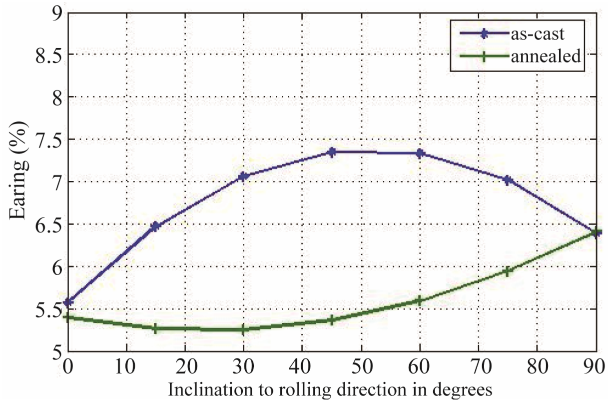


**Figure 2. Earing against inclination to rolling direction.**

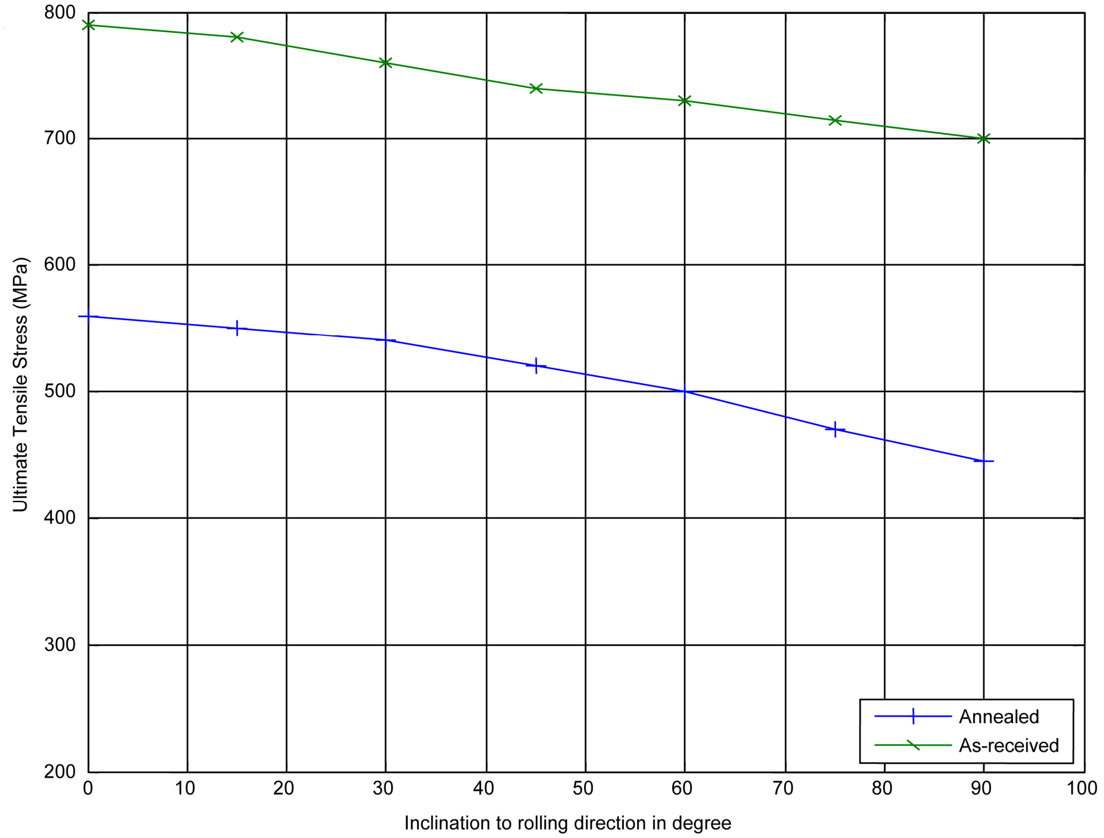


**Figure 3. Ultimate Tensile Strength against Inclination to rolling direction.**

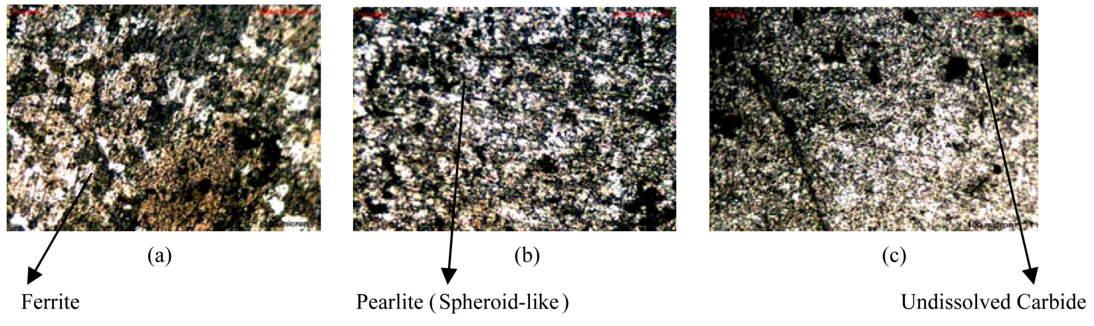


**Plate 1. Micrographs of annealed 0.1%C eutectoid steel specimens in varying directions (a) 0˚; (b) 45˚ and (c) 90˚.**

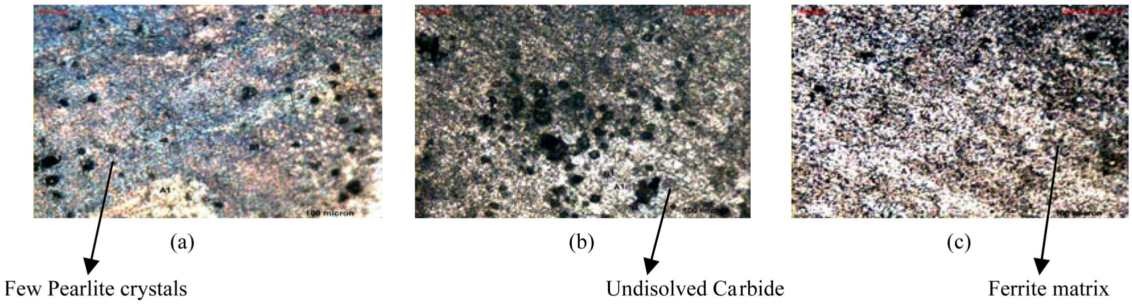


**Plate 2. Micrographs of as-received 0.1%C eutectoid steel specimens in varying directions (a) 0˚; (b) 45˚ and (c) 90˚.**

in resistance to flow thereby enhancing formability. This structural condition significantly contributed to the reduction in the amount of obstacles to the motion of dislocation during deformation hence, the progressive downward reduction in strength.

The observed trend further validates the need for the estimation of forming load in deep drawing operation in order to ensure minimal tool wear rate [11]. **Plate 2** shows the micrographs of the as-received specimens at various angles of inclination to the rolling direction. The matrices contain quite a few pearlite crystals sparsely dispersed in ferrite matrix which increases progressively from the rolling direction 0˚ (**Plate 2(a)**) to 45˚ (**Plate 2(b)**) and 90˚ (**Plate 2(c)**) respectively.

The rolling condition of the as-received specimens in this study is similar to the state of a steel undergoing normal cold drawing operation. In such a state, the original microstructure of the eutectoid steel which consists mainly of lamellar pearlite remains substantially unchanged. The difference however as observed in this study is the progressive reduction in the pearlite lamellar spacing as indicated by the change from coarse to fine crystals. The work of Toribio *et al*. [12] shows similar microstructure evolution during a continuously cold drawing of eutec- toid pearlitic steel. This microstructure condition is capa- ble of achieving remarkable increase in yield strength while the tensile strength is lowered thereby impairing the stability of spread of the article formed.

## 3.2. Drawability Behaviuor of Test Specimens

Deep drawability is the property of a material indicating its ability to be drawn to a predetermined depth (cup) without fracture. The depth to which the material is drawn is normally indicated by the cup height while the quality of the cup surface finish (degree of smoothness without tears and wrinkles) is measured by the ear in percent.

The deep drawability behavior of the test specimens is illustrated in **Figure 1**. Under the same load and other operating conditions, the test specimens demonstrated 30.5 mm and 29.5 mm cup heights for annealed and as-received respectively at 45˚ direction.

The higher cup height exhibited by the annealed test specimens may be attributed to the profound structure refinement that occurred (**Plate 1**). However, the narrow variation in cup height values for both specimens in all rolling directions is an indication that rolling direction does not influence significantly the subsequent deep drawing process.

**Figure 2** describes qualitatively the surface finish characteristics of test specimens after undergoing the process of deep drawing. Minimum ear of 5.4% occurred in the annealed specimens along the rolling direction (0˚) with peak value of 6.4% at 90˚ direction. However, the as-received specimens exhibited minimum ear of 5.6% with 7.4% maximum at 0˚ and 45˚ rolling directions respectively.

From these results, it is observed that the variation of ear for the annealed specimens is quite low, 5.4% - 6.4% resulting in a range of 1. In contrast, the as-received specimens demonstrated a rather higher ear variation, 5.6% - 7.4% which translated to a range of 1.8. The relatively wide disparity in ear value of the as-received specimens at different rolling directions becomes more obvious by the concave shape of its curve. The presence of discontinuities with other structure defects particularly inclusions, undisolved carbide and in-homogeneity in the structure coupled with high tensile strength must have been responsible for this behavior. The near linear curvature of the curve that describe the surface finish characteristics of the annealed specimens shows that the annealing process has actually aided refinement of the structure in terms of grains morphology, volume fraction and distribution

# 4. Conclusion

The deep drawability of 0.1%C eutectoid steel in an untreated condition is rather difficult due to its high tensile strength, 700 - 787 MPa coupled with obvious microstructure defects. These conditions were substantially altered by annealing. However, variation in tensile strength, ear and the cup height (limited influence) along the different rolling directions underscores the strong influence of structures anisotropy. This behavior was reasonably subdued in the annealed specimens as demonstrated by close range values of the properties investigated namely; tensile strength, 450 - 550 MPa, cup-height, 29.5 - 30.0 mm and ear, 5.4% - 6.4%.

All characteristics that promote deep drawability occurred along the rolling direction (0˚) except that the desirable tensile strength was obtained along 90˚ inclinations. The results of this study have further demonstrated that deep drawing of high strength low formability alloys (HSLFA) such as steel is also possible at ambient temperature as against the only elevated temperature asserted by Erdin *et al.* [13].

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