INFLUENCE OF EXTENSION RATES OF AISI 4140 STEEL ON TENSILE PROPERTIES

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Abstract

The objective of this research is to investigate the effect of extension rate on tensile properties of AISI 4140 steel. The steel was supplied by local vendor in Thailand and its use for some military product. The primary material testing was needed to be done in order to obtain mechanical properties. The extension rate testing was performed on tensile testing machine ranged from 300 to 500 min / min. The results were shown that when higher extension rate was applied, the tensile stress of 4140 steel was increased. In contrast with elongation, the trend was decreased according to extension rate advancement. Moreover, extension rate is not affect to deformation mode of 4140 because ductile failure remains in the same as quasi-static tensile test.

Keywords: Heat treatment, AISI 4140, extension rate, tensile properties

1. INTRODUCTION

Tensile properties of 4140 alloy steel improved mechanically by appropriate condition of strain or extension rate investigated by tensile testing method. This kind of steel was widely used for mechanical parts building and in military application because its good in mechanical properties and availability.

The effect of strain rate on tensile properties of carbon steel and aluminum is a topic to be discussed for some researchers. The properties such as tensile stress, yield stress, hardness, strain-hardening exponent etc. were the key response to be considered when strain rate was changed from quasi-static condition. Generally, advancement of strain rate can improve mechanical properties of material. The austenitic steel will be hardened because of dynamic deformation and at that time, microstructural transformation from annealing twining to mechanical twining was simultaneouly existed in austenite phase regardless of strain rate level [1]. For structural steel, the effect of extention rate or strain rate is very strong to improved tensile properties especially lower and upper yield strength were increased when, higher strain rate was applied. Grain size (according to Hall-Petch relationship) coupled with grain boundary strengthening mechanism (dislocation piles up and difficult to move) and free path dislocation movement principles are the reason to explain lower and upper yield strength improvement [2]. For strain-hardening exponent (n), it is also enhanced corresponding to elevated strain rate [3]. The failure analysis after dynamic tensile testing was performed in order to investigate type of fracture when strain rate was increased. Ductile fracture is usually found because of dimples detection by Scanning Electron Microscope [1-3]. At higher strain rate, cleavage fracture and larger of dimples were sometimes observed. The effect of strain rate on tensile mechanical properties is still important at present time leading to collect novel knowledge of dynamic properties of interested materials.

The objective of this research is to investigate tensile properties and fracture surface by varying rate of extension of 4140 alloy steel.

2. EXPERIMENTAL PROCEDURE

Material in this investigation was AISI 4140 alloy steel which supplied by local vendor in Thailand and in form of extruded rod was selected. The as-received rod diameter was approximated to 25.4 mm. However, the specimen could not track any precise information about manufacturing history so, quasi-static tensile testing was needed to obtain an initial information. The tensile specimen for quasi-static purpose was prepared

according to DIN 50125:2009 standard and shown in **Figure 1**. Additionally, the dimension of elevated extension rate testing specimen is depicted in **Figure 2** which is shorter gauge length and larger gripped ends.

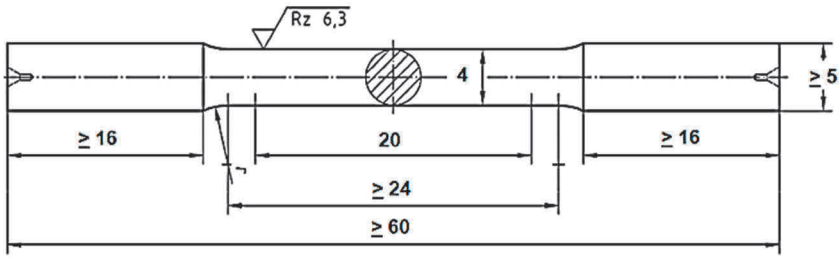
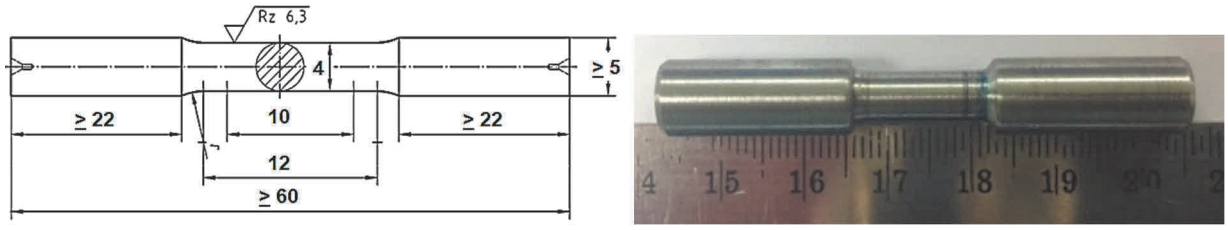


Figure 1 Schematic representation of quasi-static tensile testing for AISI 4140 steel (Dimension in mm.)



(a) (b)

Figure 2 (a) Schematic representation of elevated extension rate of tensile testing for AISI 4140 steel (b) Actual elevated extension testing specimen (Dimension in mm.)

Tensile testing performs in order to study tensile properties of hardened 4140 steel varying extension rates. The universal tensile testing machine used in this experiment is TesT GMBH model 112.100 kN.H with 100 kN maximum capacity. The gripper can be mounted with plate and rod shape specimen. Additionally, pulling rates range from 300, 400, and 500 millimeter per minute with two columns supporting crosshead can be performed. The specimens will grip on tensile testing machine and pull at ambient temperature until fracture occurs as shown in **Figure 3**. After testing, the mechanical properties were calculated according to their tensile specimen dimensions and stress-strain curves. Moreover, the data from the quasi-static tensile test temperature were used to calculate the true stress and strain which were more meaningful than the engineering stress and strain for plastic deformation analysis. The true stress and true strain were calculated using formula as in equation (1) and (2). It was noticed that true stress and engineering stress relationship (equation (1)) is not applicable when the occurrence of necking is reached [4].

$$\sigma = P(1 + e) \tag{1}$$

$$\varepsilon = ln(1 + e) \tag{2}$$

Where:

σ - The true stress (MPa)

ε - The true strain

P - The engineering stress (MPa)

e - The engineering strain

High Resolution Optical Microscope (Olympus Model DSX510) is basically used for fracture surface investigation after mechanical testing succeeded with special feature to capture topology of the fracture surface. The fracture image result of dynamic tensile testing will be captured, observed and classified into ductile, brittle, or mixed mode fracture.

Figure 3 Mounting of tensile specimen with gripper before testing operates

3. RESULTS AND DISCUSSION

3.1. Tensile properties of normal extension rate (Quasi-static)

In quasi-static mode of tensile testing, the extension rate was set up to slow level at 2 mm / min. The engineering stress-strain curve of 4140 steel was shown in **Figure 4**. The mechanical properties of 4140 steel were approximated from such curve and concluded on **Table 1**.

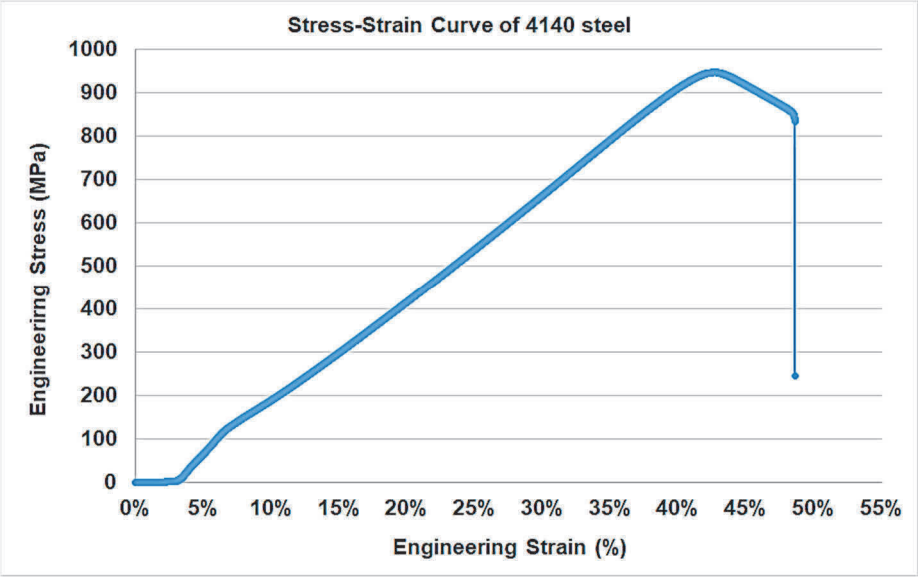


Figure 4 Engineering stress-strain curve of 4140 steel

Table 1 Mechanical properties of 4140 steel in quasi-static mode

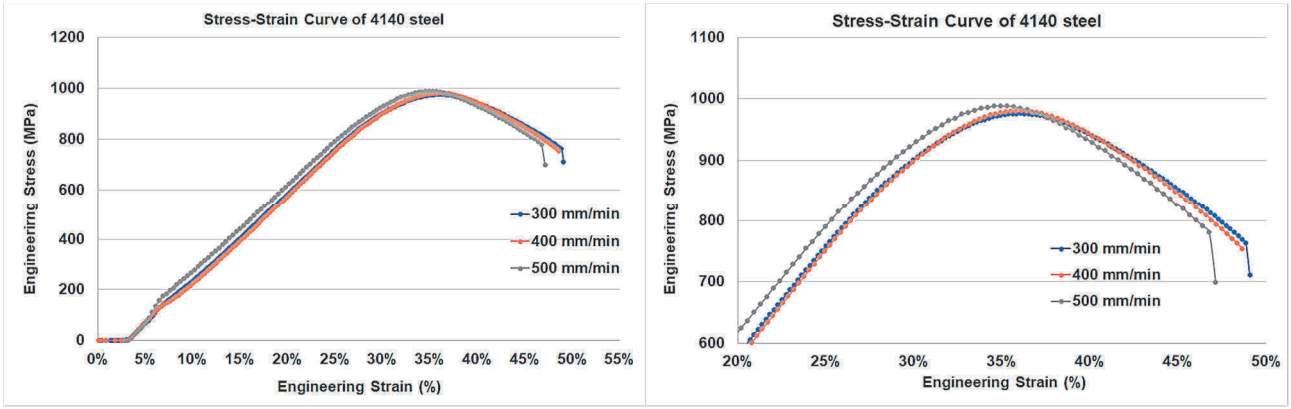
Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
844.58	998.90	48.74

3.2. Tensile properties of elevated extension rate

In elevated extension mode, the extension rates were set up at 300, 400, and 500 mm / min. The result of tensile testing was compared among extension rates and summarized on **Table 2**. The highest tensile stress of 4140 steel was achieved with 500 mm/min extension rate and the lowest elongation was also obtained. The flow curve of each extension rate was shown in **Figure 5**.

Table 2 Mechanical properties of 4140 steel with varying extension rate

Extension rate (mm / min)	Ultimate tensile stress (MPa)	Strain at break (%)
300	976.33	49.98
400	981.27	48.81
500	988.90	47.13



(a) (b)

Figure 5 Comparative engineering stress-strain curve of 4140 steel varying extension rate (a) Overall flow curve (b) Extended at high tensile stress area (≥ 600 MPa)

3.3. Fractography

Fracture surfcace of three specimens was observed by OM and depicted in **Figure 6**. They were obviously shown ductile fracture occurance in all three specimens so that the extension rate (not more than 500 mm/min) is not affected to fracture mode of 4140 steel. The cup-and-cone manner of fracture surface was also observed in all specimen as well.

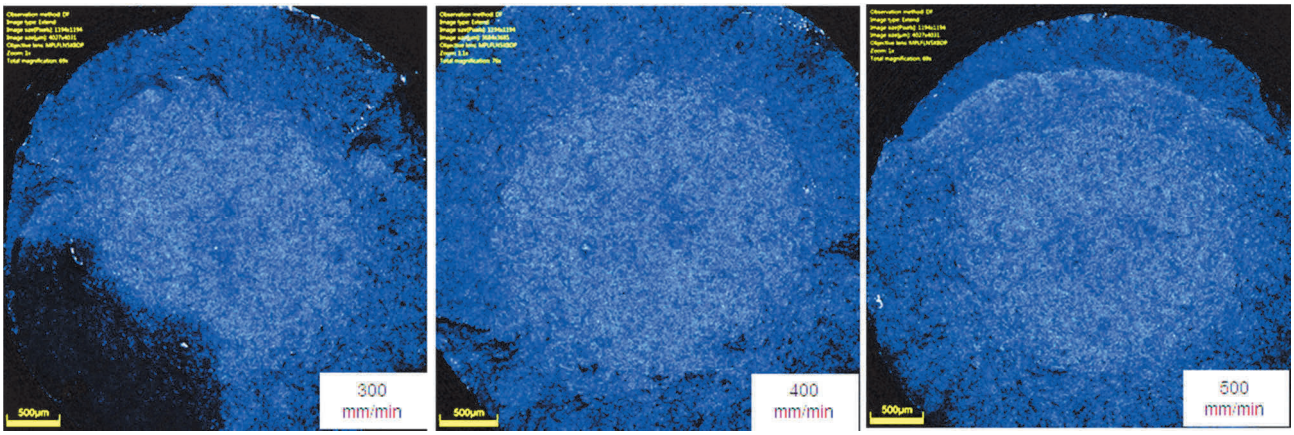


Figure 6 Comparative fracture surface of three different extension rates of 4140 steel

4. CONCLUSION

The effect of extension rate on hardened 4140 steel was investigated and concluded as followed;

1) The quasi-static test of as-received 4140 specimen was performed initially and found tensile strength, yield strength, and elongation was 998.90 MPa, 844.98 MPa, and 48.74 % respectively.
2) The tensile stress was raised with higher extension rate. The highest stress was 988.90 MPa at 500 mm/min extension rate. In contrast with lowest extension rate, the stress caused by dynamic tensile test was 976.33 MPa.
3) The fracture surface of all three different kinds of extension rate was identity to ductile fracture mode. The cup-and-cone manner was also observed.

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