



## Mechanical properties of a hot rolled stainless steel sheet

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### Abstract

This research investigated the difference between the mechanical properties of TIS 1999-2543 hot rolled stainless steel in rolled and transverse directions. Testing specimens were prepared according to ASTM E8 standard. Mechanical properties under consideration included elastic modulus, yield strength, ultimate tensile strength, and elongation at the break. All mechanical properties, with the exception of the elongation at the break, presented statistically significant difference at *p-value* less than 0.05, having greater values in rolled direction.

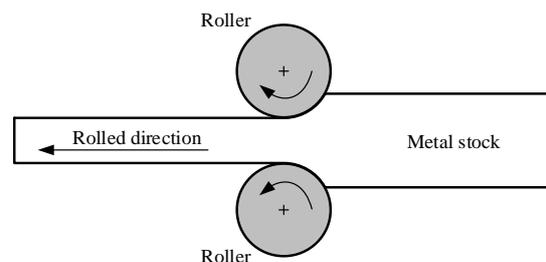
**Keywords:** TIS 1999-2543, Hot rolled stainless steel, Tensile test, Mechanical Properties

### 1. Introduction

Sheet metal produced from hot rolling process is intensively used as metal blank sheet in die pressing process for production of automotive component parts, for example, chassis frame, door, and roof [1-2]. Hot rolling process works by feeding the metal stock through rollers to reduce the thickness of materials as shown in Figure 1, to produce uniform thickness of sheet metal, typically less than 6 mm. During the hot rolling process, heat is given to metal stock rising its temperature above the re-crystallization temperature in order to restructure grain boundaries in the metal sheet into equiaxed grain structure [3]. Equiaxed grain structure indicates the isotropy of metal mechanical properties. Metal sheet which has uniform equiaxed grain throughout, its mechanical properties are expected to be isotropic [4]. Nevertheless, practically, surfaces of metal sheet subject a higher deformation than middle thickness region. Consequently, anisotropic properties may present. Anisotropy property of various hot rolled sheets has also been reported by several authors. For example, Matsumoto *et al* [5] reported tensile test result at various angles between transverse and rolled directions of hot rolled AZ31 Mg alloy. Result from the test indicated that stress-strain curves in rolled and transverse direction of metal sheet are different. Finding of Matsumoto *et al* also agrees with results from the work of Bryukhanov *et al* [6], who carried out similar experiment on the same materials. The authors revealed the anisotropy of some mechanical properties, i.e. yield stress (YS) and ultimate tensile strength (UTS) of AZ31 Mg alloy in rolled direction were lower than transverse direction whereas the inverse trend was found on elongation. In addition, Banumathy *et al* [7] also showed the in-plane

anisotropy of hot rolled Ti-16Nb alloy. YS and UTS of Ti-16Nb alloy in rolled direction were greater than transverse direction, but elongation in rolled direction was lower than transverse direction. Song *et al* [8] also reported the anisotropy of Ti-6Al-4V alloy in tensile properties and found to increase with rolling temperature.

For stainless steel, existing literatures which reported the mechanical properties of hot rolled steel were low-carbon steel by Zambrano *et al* [9] and X80 by Joo *et al* [10]. Stress-strain curve, YS, and UTS in various angles between transverse and rolled directions presented anisotropic material properties. In addition, absorbed energy of steel examined by Charpy test was also varied for each testing direction. Another stainless steel which is commonly used in automotive industry is TIS 1999-2543, to best of the authors' knowledge, no literature has been investigated its mechanical properties. Therefore, the aim of this research is to examine the mechanical properties of TIS 1999-2543 hot roll steel and analyze its anisotropy. Obtained results would greatly contribute automotive part design, determine the parameters in blanking process, and identify problem of defective parts.



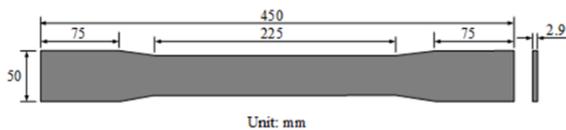
**Figure 1** Hot rolling process

**2. Materials and methods**

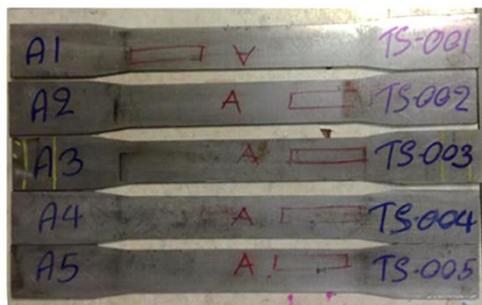
A 2.9 mm thickness of TIS 1999-2543 hot rolled stainless steel which had a chemical decomposition as shown in Table 1 was used in this research. The stainless steel sheet was shaped into testing specimens according to American Standard of Testing Materials (ASTM) E8–Standard Test Methods for Tension Testing of Metallic Materials [11] by milling process, as shown in Figure 2. Two batches of five specimens were prepared in rolled direction (RD) and transverse direction (TD), as shown in Figure 3.

**Table 1** A chemical decomposition (% wt.) of tested hot rolled stainless steel

| C    | Si  | Mn   | P     | S     | Fe   |
|------|-----|------|-------|-------|------|
| 0.09 | Tr. | 0.47 | 0.017 | 0.002 | Bal. |



(a)



(b)

**Figure 2** ASTM E8 specimens (a) and actual specimens from RD (b)

Mechanical properties of each specimen were examined with tensile test using universal testing machine (UTM) (Gotech Testing Machine, Inc.). Testing was performed at a constant cross-head velocity of 10 mm/min, equivalent initial strain rate of  $8.33 \times 10^{-4}$  /s until the specimens were broken, as shown in Figure 4. Mechanical properties under

consideration used for analysis included Elastic modulus (E), YS, UTS, and elongation at break. *F-test* and *t-test* was used to analyze significant differences between RD and TD mechanical properties, *p-value* less than or equal to 0.05 was considered as statistical significant difference.

**3. Results**

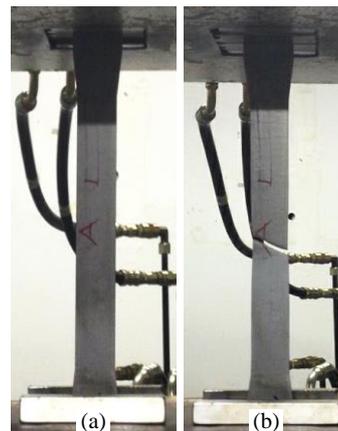
*3.1 Stress–strain curves and mechanical properties*

Stress-strain curves obtained from the test are shown in Figure 5. In addition, Table 2 also shows average values and its standard deviation of the interested mechanical properties. Average elastic modulus, YS and UTS of RD is greater than TD whereas inverse trends were found in elongations at break. Strength coefficient (*k*) and Strain hardening exponent (*n*) were obtained from regression analysis of the stress ( $\sigma$ )-strain ( $\epsilon$ ) relation in plastic deformation regions based on power-law function (Eq. 1). Average values and standard deviation of *k* and *n* values are shown in Table 3.

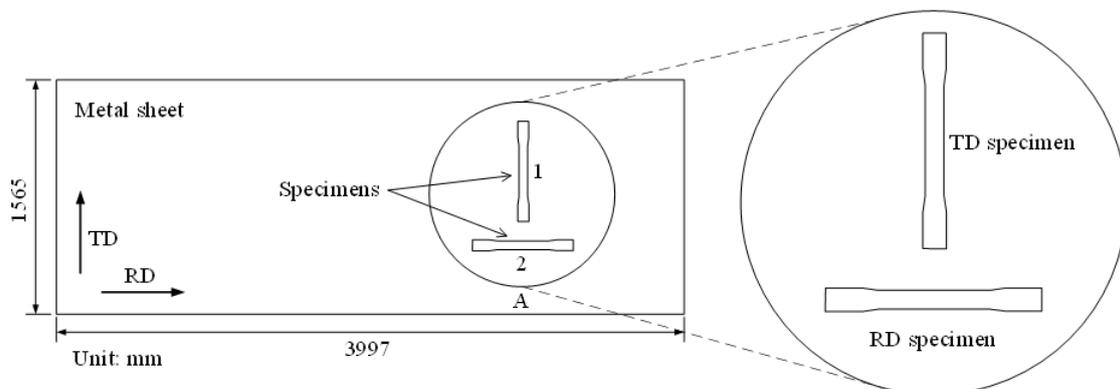
$$\sigma = k\epsilon^n \tag{1}$$

*3.2 Statistical analysis*

*P-values* of each mechanical parameter are shown in Table 2. At  $\alpha$ -value of 0.05, all mechanical properties excepted for elongation at the break were considered significant difference.



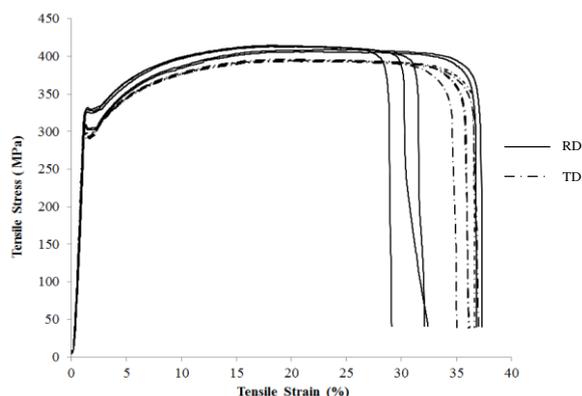
**Figure 4** Tensile test (a) experimental set up, (b) breakage of specimens



**Figure 3** Specimens RD and TD cut direction

**Table 2** Mechanical properties obtained from tensile test (n=5)

| Testing Direction       | RD                     | TD                     | p-value |
|-------------------------|------------------------|------------------------|---------|
|                         | $\mu \pm S.D.$         | $\mu \pm S.D.$         |         |
| Elastic Modulus (MPa)   | 36,941.60 $\pm$ 857.05 | 35,469.60 $\pm$ 909.08 | 0.030   |
| YS (MPa)                | 320.78 $\pm$ 11.62     | 296.83 $\pm$ 1.92      | 0.002   |
| UTS (MPa)               | 411.36 $\pm$ 3.57      | 394.79 $\pm$ 1.13      | 0.024   |
| Elongation at Break (%) | 33.57 $\pm$ 3.48       | 36.19 $\pm$ 0.74       | 0.174   |

**Figure 5** Stress–strain curves**Table 3** Strength coefficient and Strain hardening exponent (n=5)

| Testing Direction               | RD                | TD                |
|---------------------------------|-------------------|-------------------|
|                                 | $\mu \pm S.D.$    | $\mu \pm S.D.$    |
| Strength Coefficient, $k$ (MPa) | 690.78 $\pm$ 7.77 | 666.84 $\pm$ 2.57 |
| Strain Hardening Exponent, $n$  | 0.20 $\pm$ 0.01   | 0.20 $\pm$ 0.00   |

#### 4. Discussion

This research investigated mechanical properties of TIS 1999-2543 hot rolled stainless steel, the material is widely used as blank in die pressing process for production of automotive components. From the results, three of four mechanical properties present statistically significant difference between RD and TD, which were elastic modulus, YS, and UTS. Anisotropy of hot-rolled steel found in this study was agreed with study of Erturk *et al* [12] and Joo *et al* [10]. Both studies reported mechanical properties the same as in this study, exception for elastic modulus. In addition, elastic modulus of hot rolled stainless steel is also lower than general known elastic modulus of 180,000 – 200,000 MPa.

Simulation using Finite Element (FE) method is commonly performed to investigate the problems or identify optimal processing parameters in the die pressing process. Accuracy of the FE method depends strongly on material constitutive law attributed to geometric model. Various FE investigations were assumed steel sheet as isotropic and elastic modulus of 200,000 MPa [13-14], which was greater than magnitude reported in this study approximately 550 percents. Incorrect modulus leads to large difference between FE and experimental results during FE validation process. Material data obtained from tensile test in FE analysis should be used rather than material data provided from other reference sources.

Understanding mechanical properties of hot-rolled stainless steel is important for part design process. From the result, RD presented greater in most of mechanical properties

under consideration, component parts should then be designed in such a way that RD is subjected to the loading force instead of TD. In addition, knowing exact elastic modulus is useful for trading off between component part strength and weight, i.e. thickness of component parts have to increase for the lower elastic modulus.

#### 5. Conclusions

This research investigated mechanical properties of TIS 1999-2543 hot rolled steel sheet according to ASTM E8. Elastic modulus, YS, and UTS in RD are greater than TD whereas elongation at break in RD is lower than TD. The results revealed that three of four mechanical properties present statistically significant differences at p-value less than or equal to 0.05 which are elastic modulus, YS, and UTS. Therefore, mechanical properties of TIS 1999-2543 hot rolled stainless steel sheet can be considered as anisotropy.

#### 6. Acknowledgements

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