

# Simulation of Heat Affected Zone in X60 Steel



Ines Hamdi<sup>1</sup>, Zakaria Boumerzoug<sup>2\*</sup> and Fabienne Delaunois<sup>3</sup>

<sup>1</sup>Department of Chemical Industry, University of Biskra, Algeria

<sup>2</sup>Department of Mechanical Engineering, University of Biskra, Algeria

<sup>3</sup>Department of Metallurgy, University of Mons, Belgium

**Submission:** June 29, 2020; **Published:** August 24, 2020

**\*Corresponding author:** Zakaria Boumerzoug, Department of Mechanical Engineering, University of Biskra, Algeria.

Email: zboumerzoug@yahoo.fr

## Abstract

This research is aimed to simulate the heat affected zone (HAZ) in X60 steel after thermal cycle simulation of welding by using specific simulation equipment. Optical microscopy and microhardness tests were used as techniques of characterization. The obtained results indicated that the HAZ can be divided in different sub-zones. The formation of microstructures in each zone depends on the level of thermal exposure. Microhardness measurements showed an increase of microhardness in the most examined sub zones of HAZ compared with the microhardness in the base metal.

**Keywords:** Welding; Heat affected zone; Microstructure; X60 steel; Thermal cycle simulation

**Abbreviations:** HAZ: Heat Affected Zone; Hv: Hardness Vickers; FZ: Fusion Zone; BM: Base Metal; OM: Optical Microscopy; WF: Widmanstätten Ferrite; AF: Acicular Ferrite; XRD: X-Ray Diffraction

## Introduction

Microalloyed steels have allocated a special attention as pipeline steels due to high strength and proper toughness [1]. These alloys are commonly employed in the high-pressure gas conducting [2]. Usually these steels exhibit microstructure mainly composed of ferrite that can take different morphologies, such as acicular or polygonal [3]. Among these steels, there is X60 steel which belongs to low-carbon and thermo-mechanically controlled steels category which constituted of ferrite and pearlite phases [4]. This steel is preferable for the pipeline project and it is welded by arc welding process in pipeline construction.

Welding is a process of joining materials into one piece. Generally, welding is the preferred joining method

and most common steels are weldable [5]. Heat generated during welding induces an important temperature gradient in and around the welded area. Three main different zones were recorded in welded joint: fusion zone (FZ), heat affected zone (HAZ), and base metal (BM). The region between the FZ and BM is known as the heat affected zone (HAZ) which is thermally affected by the welding treatment. The changes of microstructures in the HAZ depend on the level of thermal exposure and are varying with distance from the weld metal zone. The heat affected zone (HAZ) formed during welding is an area in which some structural changes in the welded material take place as the result of experienced

temperature [6]. The main difficulty associated with welding is the prevention of unexpected deterioration of properties as a result of the microstructure evolutions which reduce the resistance to brittle fracture in the heat-affected zone (HAZ) [7]. Properties of the HAZ are different from those of the base material. According to the literature, the HAZ is the most problematic area in the high strength steels weld. For this reason, many research works investigated this critical zone in welded joint.

However, the investigation of the HAZ in the real weldments is not easy, because it is not possible to obtain an appropriate specimen at very narrow locations in the HAZ [8,9]. To evaluate the HAZ's properties, thermal cycle simulation is one the best approaches for the investigation of HAZ. It gives more information about changes in the temperature and different microstructures obtained in HAZ caused by welding [10]. In addition, weld thermal cycle simulation can be used for optimizing the welding technology since it enables some mechanical testing for properties that cannot be made on real welded joints because of small width of HAZ [11]. For example, in our previous contribution to the understanding of the different microstructures in welded joints of Inc 738 LC superalloy using the thermal cycle simulation [12], we found that the obtained microstructures by thermal cycle simulation of welding correspond to those observed in the same zone of the real welded joint realized by TIG welding. In addition, in

our recent work [13], we found that HAZ in 2014 aluminum alloy, investigated by a thermal cycle simulation, is not a homogeneous zone but it is composed with different subzones.

Although massive research has been conducted on X60 steel, however, there has been limited information about the HAZ in welded X60 steel [4,14,15]. For example, Kec et al. [14] investigated mechanical properties and microstructure of welded X60 line-pipe steel. They found that the lowest impact energy was measured in the heat affected zone and seam weld due to the presence of heterogeneous microstructure consisting of grain boundary ferrite, polygonal ferrite and Widmanstätten ferrite. Cvetkovski & Brkovski [15], concluded that the hardness test showed the max hardness is in the weld metal, and slightly better hardness was measured in the HAZ, but a base material showed the lowest values. Gholamreza & Jandaghi [4] observed finer grains in HAZ than in the base metal in X60 steel. In this context, the purpose of this present study was to investigate the HAZ in X60 steel by a thermal cycle simulation. Thermal cycle simulator was used and the heat-treated steel was characterized by an optical microscopy and hardness measurements.

### Materials and Methods

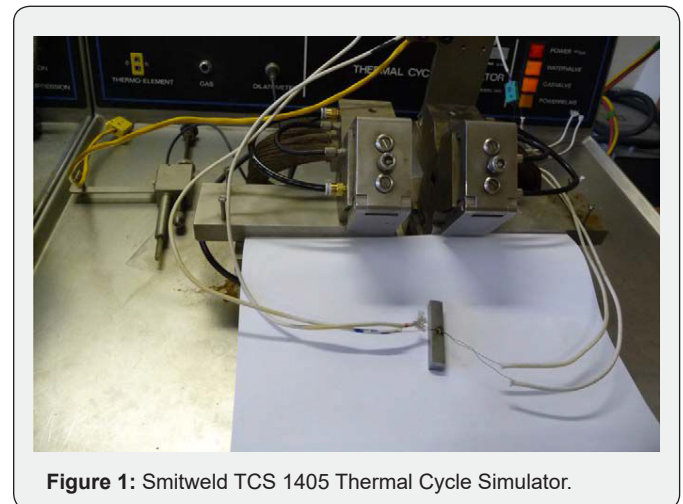
The chemical composition of the base material is shown in Table 1. A microstructure representative of the HAZ was produced

**Table 1:** Chemical Composition of the Base Material.

C	Si	Mn	P	S	Cr	Mo	Ni	V	Al	Cu	N	Zr	Ti
0.07	0.9	1.71	0.008	0.013	0.04	<0.01	0.03	<0.01	<0.01	0.1	0.04	<0.01	0.01

Specimens used for optical microscopic observations were polished with SiC paper up to grade 2000 and with 0.3 $\mu$ m diamond paste afterwards and etched with 4% Nital solution. The hardness across the welded joint was measured by Vickers microhardness tester (autovick hardness tester) using 200gf. Five measurements were performed for every identified sub-zone in the HAZ and the average values were calculated.

using thermal cycle simulation and the HAZ microstructure was characterized with optical microscopy and hardness measurement. For thermal cycle simulation study, specimens 10mm thick 10 $\times$ 12 mm<sup>2</sup> of the X60 steel, were heat treated with the simulator tests Smitweld TCS 1405 (Figure 1), for temperatures ranging between 500-1277 $^{\circ}$ C. The Smitweld TCS1405 simulator is equipped to carry out computer-controlled temperature cycles that consist of a rapid heating followed by a cooling treatment.



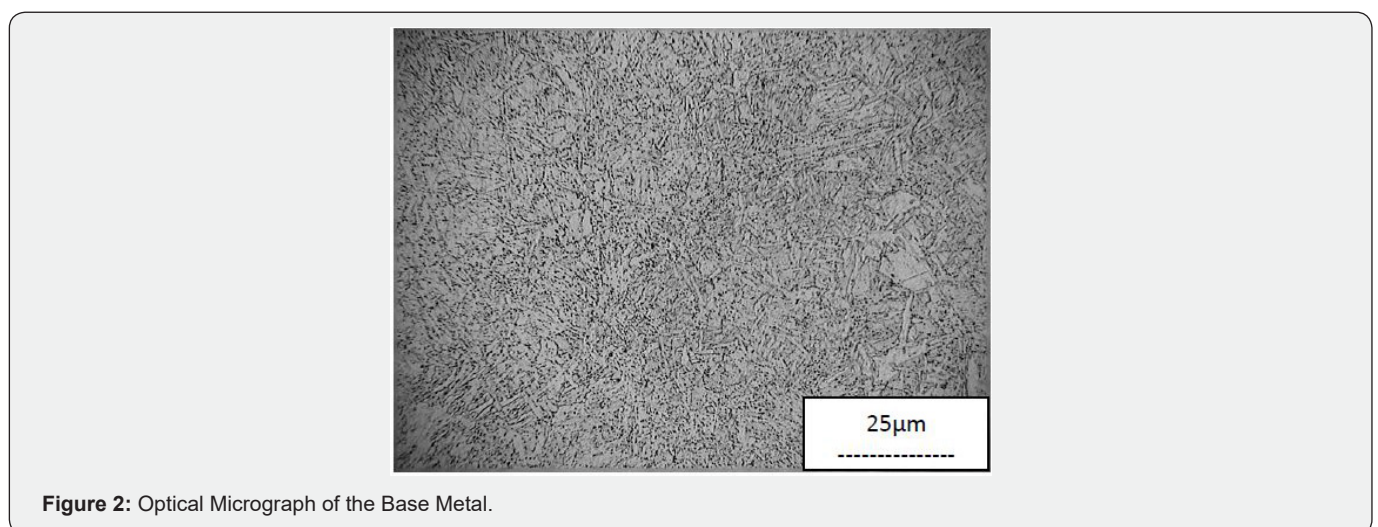
**Figure 1:** Smitweld TCS 1405 Thermal Cycle Simulator.

### Results and Discussion

#### Microstructures Evolution of the Base Metal

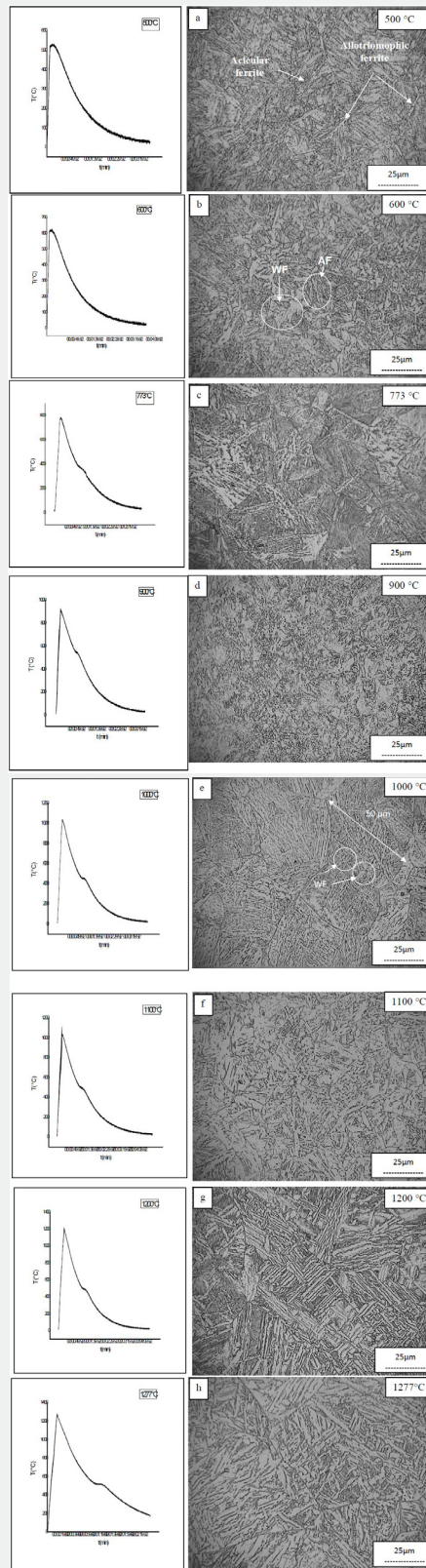
The results of OM observation show that the microstructure of the base metal consists of finer ferrite

grains (white) and dispersed colonies of pearlite (black) (Figure 2). The mean grain size of ferrites was



**Figure 2:** Optical Micrograph of the Base Metal.

Heat treated of the Base Metal in Simulator



**Figure 3:** Optical Micrographs of Simulated HAZ at Different Heat Treatment States (a) 500, (b) 600, (c) 773, (d) 900, (e) 1000, f)1100, g)1200, and h) 1277°C.

The optical micrographs of the heat-treated base metal at different temperature in a simulator are shown in Figure 3. First of all, the microstructure of X60 steel heat treated at 500°C corresponds to the acicular ferrite with a small amount of allotriomorphic ferrite (Figure 3a). The allotriomorph grows rapidly along the austenite grain boundary (which is an easy diffusion path) but thickens more slowly [16]. It has been reported that the microstructure of a hypoeutectoid steel that is cooled rapidly from austenite but at a rate that still permits the austenite to transform into ferrite plus pearlite will contain the Widmanstätten ferrite and fine pearlite [17]. The microstructure of X60 steel heat treated at 600°C shows a slight change (Figure 3b) in comparison with the previous heat treatment; because the Widmanstätten ferrite plates in a matrix with acicular ferrite are more visible as indicated by circles. By increasing the peak temperature to 773°C, grain growth reaction was developed (Figure 3c) and the mean grain size of ferrite was approximately 25µm. At 900°C, grain refinements by recrystallization reaction with a spheroidization of cementite are the main reactions at this temperature (Figure 3d). In the spheroidized microstructure, the carbides are discrete globules embedded within the ferritic matrix and resident on grain boundaries. Steels with this microstructure are in their softest state and are most easily mechanically formed [17].

At 1000°C, an exaggerate grains growth reaction was developed, because some grains have more than 50µm (Figure

3e). In addition, growth reactions of plates of WF plates are also observed. By increasing the heat treatment to 1100°C, new morphology was formed (Figure 3f), because a recrystallization reaction is observed in the ferrite matrix. At 1200°C, the structure consists of a dominance of the acicular ferrite (Figure 3g). Finally, at high temperature of heating (1277°C) which is close to the solidus line, a coarsening of AF was produced with grain growth (Figure 3h). At this state, the mean grain size of ferrite was approximately 75µm. Joodaki et al. [1] observed a significant grain growth which is detectable after annealing at 1200°C. To end this, annealing treatment at former temperature leads to significant grain growth and consequently can be effective on decreasing the mechanical properties. Based on these observations, the HAZ in welded X60 steel is formed with different subzones, and each zone has its own microstructure.

Based on the microstructural observations of X60 steel after thermal cycle simulation at different temperature, a schematic illustration of HAZ is proposed (Figure 4). According to the effect of temperature on each area in HAZ, it can be subdivided into five successive sub-zones from the base metal to the fusion zone as mentioned from subzone (I) to (V). Sub-zone I contains allotriomorphic ferrite with acicular ferrite, subzone II contains finer grains with spherical cementite, subzone III is formed with Widmanstätten ferrite and acicular ferrite, sub-zone IV, characterized by a recrystallized ferrite, and finally a sub-zone V is occupied by acicular ferrite.

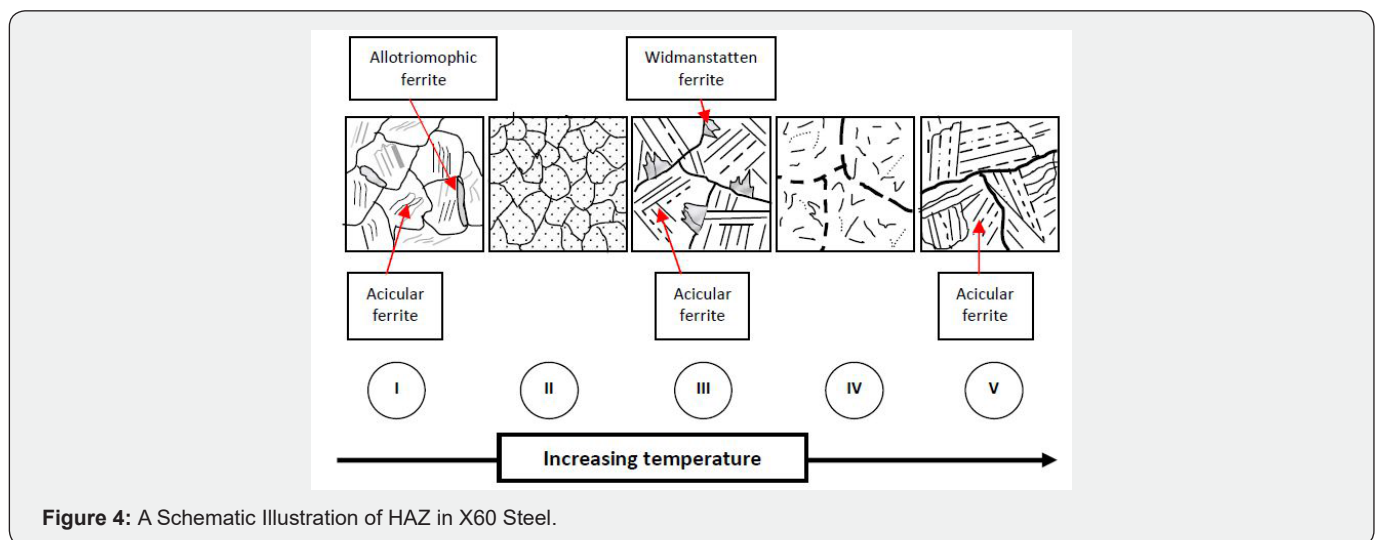


Figure 4: A Schematic Illustration of HAZ in X60 Steel.

**X-Ray Diffraction**

Figure 5 shows the X-ray diffraction diagrams obtained from X60 steel samples submitted to different thermal cycles simulation (500, 600, 773, 900, 1000, 1100, 1200, and 1277°C). According to Figure 5, there is no evidence of phase changes when comparing between base metal, and the heat-treated sample by thermal cycle’s simulation. The five peaks revealed in all XRD diagrams correspond to the ferrite phase (matrix). Consequently,

there was not a real phase transformation after different thermal cycles, because the same phase (Ferrite) revealed in the base metal have been detected by XRD in the heat-treated samples by thermal cycle simulations. But the morphology of ferrite changes after each treatment as observed in optical microscopy.

**Microhardness Measurements**

Figure 6 presents the hardness curve of the simulated X60 steel at different temperature. Generally, the hardness values

of heat-treated samples are more than the hardness of the BM, except the heat-treated sample at 600°C which is less than the BM. The highest hardness is measured for the heat-treated sample at 773°C which is due probably to the hidden transformation such as carbides formation. The lowest hardness values were measured in the heated samples at high temperature (more than 1000°C) which corresponds to the nearest zone to the fusion zone in real welded joint. We have found the same results in our previous work

related to the investigation of the HAZ in stainless steel 304L by thermal cycle simulation; i.e., by increasing the temperature, the HAZ becomes softer which corresponds to the nearest subzone to the FZ [18]. This softening phenomenon is due to the grain growth and the dissolution of carbides. We conclude from the hardness measurements in heat treated X60 steel at different temperature, that the HAZ is not a homogeneous zone.

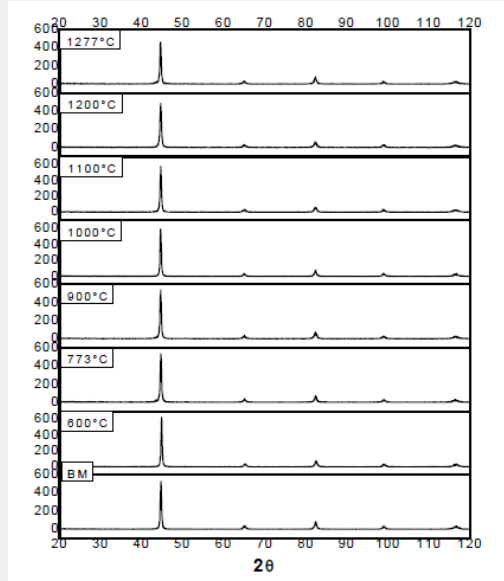


Figure 5: X-Ray Diffraction Diagrams from the Base Metal, and Samples Obtained after each Thermal Cycle of X60 Steel.

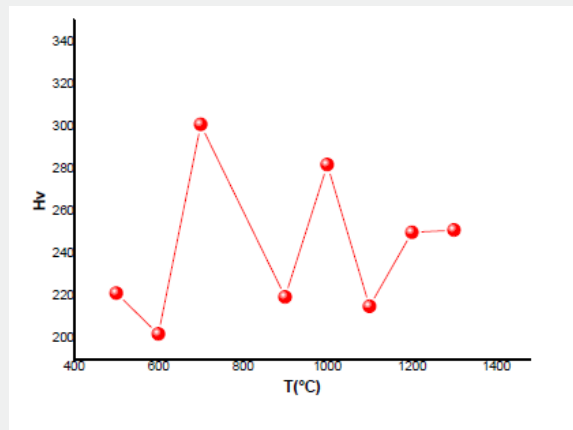


Figure 6: Hardness Curve of the Simulated X60 Steel at Different Temperature.

### Conclusion

a) The present work is a contribution to understand the different microstructures in the simulated HAZ of

b) X60 steel by using the thermal cycle simulation. We can

conclude that:

c) Study with thermal cycle simulation can give more details of each region in the HAZ.

d) Depending on temperature, different forms of ferrite can nucleate such as Widmanstätten ferrite, and acicular ferrite.

e) Depending on temperature, recrystallization reaction, grain growth reaction, and spheroidization of cementite can be also observed.

f) Based on these observations, the HAZ in welded X60 steel is formed with different sub-zones, and each zone has its own microstructure.

g) According to XRD analysis, there was not a phase transformation of the base metal after thermal cycle simulation.

a) Microhardness measurements showed an increase of microhardness in the most heat-treated samples and the highest values of the microhardness were found in the heat-treated sample at 773°C. From the hardness measurements, the HAZ is not a homogeneous zone.

### References

- Joodaki R, Gheisari K, Alavi ZS, Eskandari M (2017) Effect of annealing treatments on the microstructure and texture development in API 5L X60 microalloyed pipeline steel. JMEPEG.
- Hashemi SH (2011) Strength–hardness statistical correlation in API X65 steel. Mat Sci and Eng A 528(3): 1648-1655.
- Muniz TF, Trindade VB, Lúcio de Faria G (2015) Effect of some heat treatments on microstructure and mechanical properties of microalloyed low carbon steel aiming to attend the oil and gas industry. 23<sup>rd</sup> ABCM International Congress of Mechanical Engineering December, Rio de Janeiro RJ Brazil p. 6-11.
- Khalaj G, Jandaghi M, Pouraliakbar H, Gholami A (2017) Microalloyed steel welds by HF-ERW technique: Novel PWHT cycles, microstructure evolution and mechanical properties enhancement. Inter J of Press Vess and Pip 152: 15-26.
- Boumerzoug Z, Derfouf C, Baudin T (2010) Effect of Welding on Microstructure and Mechanical Properties of Industrial Low Carbon Steel. Eng 2: 502-506.
- Śloderbach Z, Pająk J (2015) Determination of ranges of components of heat affected zone including changes of structure. Arch of metal and mater 60(4): 2607-2612.
- Abson DJ, Tkach Y, Hadley I, Wright VS, Burdekin FM (2006) A review of postweld heat treatment code exemptions. Weld J 85(3): 63-69.
- Samardžić I, Stoić A, Kozak D, Kladaric I, Dunder M (2013) Application of Weld Thermal Cycle Simulator in Manufacturing Engineering. J of Manufac and Indust Eng 12(1-2): 7-11.
- Dunder M, Vuherer T, Kladaric I (2010) Weldability Investigation of TStE 420 after Weld Thermal Cycle Simulation. Strojarstvo 52(2): 97-104.
- Górka J, Janicki D, Fidali M, Jamrozik W (2017) Thermographic assessment of the HAZ Properties and structure of thermomechanically treated steel. Int J Thermophys pp. 38-183.
- Dunder M, Samardžić I, Vuherer T (2015) Weldability Investigation Steel P91 by Weld Thermal Cycle Simulation. Metalurgija 54: 539-542.
- Boumerzoug Z, Cherif S (2017) Thermal cycle simulation of welding process in Inc 738 LC superalloy. K Eng Mater 735: 75-79.
- Raouache E, Boumerzoug Z, Delaunois F, Khalfallah F (2020) Investigation by Thermal Cycle Simulation of Heat Affected Zone in Welded AA2014 Aluminum Alloy. Res Dev Material Sci 13(3).
- Kec J, Černý I, Poloch A, Kyselá B, Poupá M, et al. (2019) Investigation of mechanical properties and microstructure of X60 line-pipe steel. ICSI The 3<sup>rd</sup> International Conference on Structural Integrity. Procedia Structural Integrity 17: 230-237.
- Cvetkovski S, Brkovski D (2016) Optimising technology for production of high frequency welded pipes made of X60 steel. Scientific Proceedings XIII International Congress Machines Technologies. Materials 10(12).
- Manna R, Lecture, Time Temperature Transformation (TTT) Diagrams, Metallurgy University of Cambridge.
- Meyrick G (2001) Steel, Class Notes and lecture material For MSE 651.
- Hamza S, Boumerzoug Z, Raouache E, Delaunois F (2019) Simulated heat affected zones in welded stainless steel 304L. Acta Meta Slov 25(3): 142-149.



This work is licensed under Creative Commons Attribution 4.0 License  
DOI: [10.19080/IMST.2020.02.555582](https://doi.org/10.19080/IMST.2020.02.555582)

### Your next submission with Juniper Publishers will reach you the below assets

- Quality Editorial service
- Swift Peer Review
- Reprints availability
- E-prints Service
- Manuscript Podcast for convenient understanding
- Global attainment for your research
- Manuscript accessibility in different formats  
( Pdf, E-pub, Full Text, Audio)
- Unceasing customer service

Track the below URL for one-step submission

<https://juniperpublishers.com/online-submission.php>