International Journal of Civil and Structural Engineering– IJCSE
Volume 2 : Issue 1 *[ISSN : 2372-3971]*
Publication Date: 30 April, 2015

Effect of Specimen Preparation Methods for Tension Test on Design of Cold-Formed Steel Members

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***Abstract*—Performance of a structure is usually determined by the amount of permitted deformation. Some measured properties that must be considered when designing a cold formed steel structure include tensile strength, yield strength and modulus of elasticity. The other important property is ductility that is the ability for plastic deformation in tension or shear. Ductility controls the amount a material can be cold formed that is the process used when producing cold formed steel members. Steel properties that have direct or indirect influence on formability and structural element performance are tensile strength, yield strength and modulus of elasticity, ductility, hardness, stress hardening exponent, plastic strain ratio. All of these parameters can be determined by tensile test, except hardness. The stress strain curve is generated by pulling a metal specimen under axial tension to failure. ASTM E8/E8M Standard Test Methods For Tension Testing Metallic Material used for determination of tensile strength, yield strength and modulus of elasticity, percent elongation at failure and reduction of area. The robust tension test can be done by reliable test specimen preparation process. Test specimen can be prepared by different methods by cutting specimen form sheet metal. Common methods are for cutting sheet metal will be investigated. Inspected methods are computer numerical control laser cutting, plasma cutting and wire electrical discharge machine cutting. All these methods have own advantages, but different effects on specimens. These effects on specimen are not only production of high precision test specimen, but also heat effects and different roughness values at cutting surface on the test specimen. In the present study, an attempt has been made to investigate the effect of cutting methods on the tension test specimen. As a result, investigations will be conducted to determine the most favorable method for preparing tension test specimen for design of cold formed steel member.**

Keywords—Tensile testing, Sheet metals, Experiments, Cutting methods .

I. Introduction

With a good knowledge of materials an ability to sustain a load safely before breaking or deformed has been the main issue in many studies such as selecting material types, dimensioning, combining each member to create a well-designed structure during life. Metals, specifically sheet metals are used in a wide range of industry such as packaging, containers, automobiles, construction industry.

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Steel material used in building needs a heavily production process and it has a big cost to be manufactured. So the material amount used in constructions must be reduced in order to achieve a non-polluted environment due to heavy steel production industry. The reduction of steel has to be managed by lowering the weight of the steel that used in construction by a qualified design without lowering the quality of the material. [2]. So, it is needed to understand the behavior of the material or mechanical properties under various tests such as tensile testing, compression or flexural testing.

Since, the strength of the material is the main issue in determining the enough plastic deformation that the material can withstand, the behavior of the material is inspected under various tests like tensile testing. Tension tests provide information on the strength and ductility of materials under uniaxial tensile stresses. This information may be useful in comparisons of materials, alloy development, quality control, and design under certain conditions. Tensile properties are often used to examine the behavior of the material under uniaxial loading. It is going to be examining the most useful method to prepare the tension test specimen for design of cold form steel member [3]. Sheet metal forming is the process that materials undergo permanent deformation by cold forming to produce the member. The process is carried out by in the plane of the sheet by tensile forces with high ratio of surface area to thickness.

Tension specimen can be prepared by different methods from cold formed sheet metal. Common cutting methods will be examined. Inspected methods are computer numerical control laser cutting with oxygen, laser cutting wire nitrogen and wire electrical discharge machine cutting. All these methods have own advantages, but different effects on specimens. Some measured properties that must be considered when designing a cold formed steel structure include tensile strength, yield strength and modulus of elasticity. The other important property is ductility that is the ability for plastic deformation in tension or shear. Ductility controls the amount a material can be cold formed that is the process used when producing cold formed steel members [5]. Ductility is the measure of how much the material can be deformed before fractures. Ductility is rarely incorporated directly in the design; rather, it is included in material specifications to ensure quality and toughness.

II. Experimental procedure

In this study the specimens are prepared and tested according ASTM E8/E8M [1]. Standard Test Methods for Tension Testing Metallic Material as plotted in Figure1. The

ASTM E8/E8M standard is used for determination of tensile strength, yield strength and modulus of elasticity, percent elongation at failure and reduction of area.

This study provides some of the more important issues related to tensile testing of the sheet member. These are;

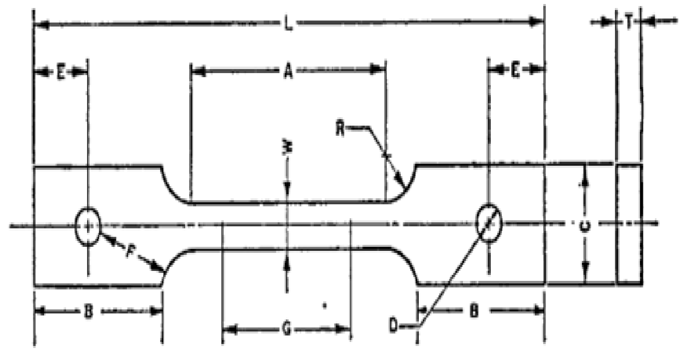
- Preparing the test specimens (cutting and dimensioning)
- Mythology of the test and testing machine
- Data analysis

A. *Preparing the Specimens (Cutting and Dimensioning)*

The sheet metals will be cut from cold formed metal sheet by different cutting methods. Common methods are for cutting sheet metal will be investigated. Inspected methods are computer numerical control laser cutting with oxygen, laser cutting wire nitrogen and wire electrical discharge machine cutting.

Numerical control laser cutting; Laser cutting works by directing the output of a high-power laser, by computer, at the material to be cut. The material then melts, burns, vaporizes away, or is blown away by a jet of gas which could be oxygen or nitrogen. For thicker sheets to be cut to need higher energy and higher power so as gaseous nitrogen is used instead of oxygen. In this cut method, ultrasonic vibration of a tool in the machining of hard, brittle materials is utilized. The process consists two methods; one involves abrasive slurry with ultrasonic vibration of non-rotating tool and ultrasonic vibration of rotating diamond core drill. Material removal occurs. Advantages of laser cutting over mechanical cutting include easier work holding and reduced contamination of work piece. Laser cutting of metals has the advantages over plasma cutting of being more precise and using less energy when cutting sheet metal; however, most industrial lasers cannot cut through the greater metal thickness that plasma can. The main disadvantage of laser cutting is higher power consumption. [4].

Wire electrical discharge machine cutting; mostly used in automotive and general manufacturing applications. It is generally applicable to small production and also applicable to larger plot productions in higher tooling. Due to high pressures created by the electrical discharge machine which tend to separate the tooling from the work piece the machine must be rigid enough to withstand that force. Using electrical discharge machine for cutting the sheet metal specimen will create heat damage on the member especially on the arc of contact. To avoid this heat problem cutting process is carried out under water and it is recommended to decrease the feed speed during cutting. [6]. Some of the advantages of electrical discharge machines are complex shapes that would otherwise be difficult to produce with conventional cutting tools, extremely hard materials, very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure can be cut by this method.



	Dimensions, mm [in.]
G—Gauge length	50.0 ± 0.1 [2.000 ± 0.005]
W—Width (Note 1)	12.5 ± 0.2 [0.500 ± 0.010]
T—Thickness, max (Note 2)	16 [0.625]
R—Radius of fillet, min (Note 3)	13 [0.5]
L—Overall length, min	200 [8]
A—Length of reduced section, min	57 [2.25]
B—Length of grip section, min	50 [2]
C—Width of grip section, approximate	50 [2]
D—Diameter of hole for pin, min (Note 4)	13 [0.5]
E—Edge distance from pin, approximate	40 [1.5]
F—Distance from hole to fillet, min	13 [0.5]

Figure 1. Pin-loaded tension test specimen with 50-mm [2-in.] gauge length, ASTM E8/E8M-11

B. *Specimen Dimensioning*

Standard tensile tests are run on "dog-bone" shaped specimens to obtain Young`s Modulus (stiffness), yield point, and yield strength. Prior to the test, one must prepare the specimen. Use the most suitable and available materials for intended use and to have better and accurate results the samples must be prepared properly. The most important part of the specimen is gauge section. In relative with other parts of the specimen we reduce the gage section so that deformation and failure will be localized in that region. According to ASTM E8M standardization the specimen dimensions were drawn out, as seen in the Figure 2.

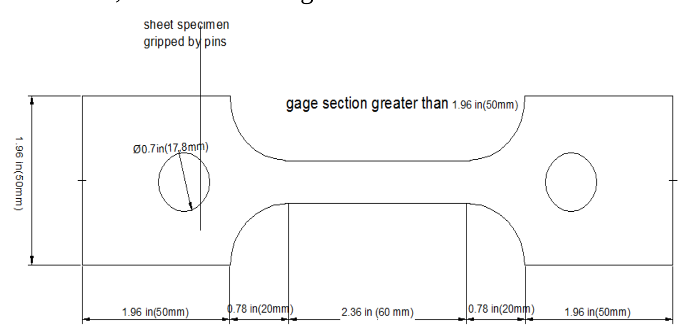


Figure 2. The geometric configuration of used sheet sample in this study, according to ASTM E8M standardization.

The distances between the ends of the gauge section, and the shoulders should be great enough so that the larger ends do not constrain deformation within the gauge section, and the gauge length should be greater relative to its diameter. Otherwise, the stress state will be more complex than simple tension. The gauge cross-sectional area is reduced so that the failure will be localized in this zone. [3].

C. Mythology of the Test and Testing Machine

Universal testing machines used for tension testing shall conform to the requirements. The forces used in determining tensile strength and yield strength shall be verified within the force application range of the testing machine. The test machine shall be set up and zeroed in such a manner that zero force indication signifies a state of zero force on the specimen. Upon request, the laboratory should be capable of demonstrating (perhaps through time, force, displacement) that the test speeds used conform to the requirements of ASTM E8/E8M-11 [6].

Universal testing machine is used in this study to test the tensile test specimen with a computer control. With modern computer control, it is possible to conduct tests based on the control of calculating variables such as true stress or strain intensity factor. Specimens will be mounted in the machine between two parallel moveable grips. There are two main hand wheel controls, one for applying the load and the other for releasing the load. After starting the test, a recorder will plot the stress-strain curve on the computer program during the test itself. The laboratory should follow documented procedures to ensure that machining or other preparation generates specimens conforming to applicable tolerances and requirements of ASTM E8/E8M.

III. Result and discussions

Effect of test specimen preparation of tension test is carried out on three different cutting methods with three different thicknesses. Selected cutting methods are laser cutting with oxygen, laser cutting with nitrogen and wire electrical discharge machine cutting. Purpose of selecting different cutting methods on different thicknesses is to examine heat effects and different roughness values at cutting surface on the test specimen.

Specimens are prepared on three directions from the sheet metals. These directions are rolling direction, perpendicular to the rolling direction and 45° with rolling directions. For statistical analysis, blocking is implemented and the number of blocks is equal to two is selected. For this reason 54 different samples are prepared. Prepared specimens for each thickness's shown in Figure 3.

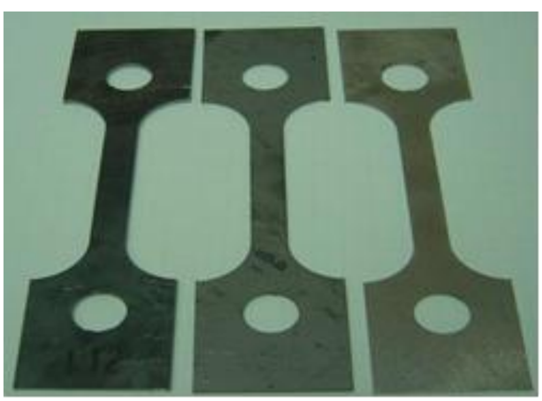


Figure 3. Prepared specimens with different thicknesses

Textures on cutting surfaces are investigated by motorized 16:1 microscope with high resolution. 45° with rolling direction specimens are selected. Captured images with respect to the each cutting method with each thickness are shown in Figure 4-6. Cutting surface textures are composed of three components; roughness, waviness and form. Each cutting method surface texture reveals a specific form of unevenness. For both laser cutting methods cut surface can reveal two zones: the upper one in the area of the laser beam entrance side and the lower one, in the area of the laser beam exit side. But however, wire electrical discharge machine cutting has a uniform pattern for both sides. Comparison of roughness heights and widths of three methods biggest values is observed in laser cutting with nitrogen method. From waviness point of view, biggest values observed in laser cutting with oxygen method. Among these three methods, electrical discharge machine quilting has a more uniform texture without any slags.

Tensile tests were performed using an AGX-300 universal testing machine. A force controlled loading was applied to each specimen with a slow rate. Selected sheet thicknesses, average yield stresses and tensile strengths are tabulated in Table 1.

TABLE I. NOMINAL SHEET THICKNESSES AND STRESSES OF THE TEST SPECIMENS

Thickness (mm)	Yield stresses (MPa)	Tensile strengths (MPa)
0.80	235.43	386.19
2.00	293.46	406.86
3.00	285.85	396.34

Effect of test specimen preparation of tension test is reviewed by using one-way analysis of variance (ANOVA). ANOVA is used to determine whether there are any significant differences between the means of three or more independent groups. For the validity of the results, some assumptions have been checked to hold before the technique is applied. These are;

- The dependent variable is normally distributed in each group that is being compared in the ANOVA.
- There needs to be homogeneity of variances.

Validation of the first assumption, Kolmogorov-Smirnov and Shapiro-Wilk tests are performed. Test of normality tabulated in Table 2. All the p-values are greater than 0.05, normally distributed assumption is satisfied. Validation of the second assumption Levene statistic test is performed. The results of the test are given Table 3. All the p-values are greater than 0.05, homogeneity of variances assumption is satisfied.

ANOVA analysis, is given Table 4., showed that the heat effects and different roughness values at cutting surface on the tension test specimen was not significant at the $p<0.05$ level for three different cutting methods with three different thicknesses [highest $F(2,15)=2.505$, $p=0.115$].

TABLE II. KOLMOGOROW –SMIRNOV AND SHAPIRO-WILK TEST RESULTS

CM		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	*df*	*Sig.*	*Statistic*	*df*	*Sig.*
TS_3mm	1	,281	6	,149	,813	6	,077
	2	,320	6	,055	,720	6	,010
	3	,137	6	,200*	,988	6	,983
TS_2mm	1	,220	6	,200*	,902	6	,383
	2	,203	6	,200*	,937	6	,632
	3	,249	6	,200*	,870	6	,227
TS_0.8mm	1	,201	6	,200*	,964	6	,847
	2	,333	6	,036	,794	6	,052
	3	,231	6	,200*	,961	6	,830
YS_3mm	1	,233	6	,200*	,900	6	,374
	2	,233	6	,200*	,828	6	,104
	3	,246	6	,200*	,839	6	,127
YS_2mm	1	,290	6	,125	,886	6	,296
	2	,275	6	,174	,894	6	,338
	3	,189	6	,200*	,930	6	,579
YS_0.8mm	1	,205	6	,200*	,948	6	,724
	2	,200	6	,200*	,876	6	,253
	3	,196	6	,200*	,922	6	,517

TABLE III. LEVENE STATISTICAL TEST RESULTS

	Levene Statistic	df1	df2	Sig.
TS_3mm	1,754	2	15	,207
TS_2mm	,187	2	15	,831
TS_0.8mm	2,486	2	15	,117
YS_3mm	,281	2	15	,759
YS_2mm	1,653	2	15	,225
YS_0.8mm	2,497	2	15	,116

TABLE IV. SUMMARY TABLE

TS_3mm	**Between Groups**	128,222	2	64,111	2,392	,125
	Within Groups	401,993	15	26,800		
	Total	530,215	17			
TS_2mm	**Between Groups**	14,067	2	7,033	,172	,844
	Within Groups	614,751	15	40,983		
	Total	628,818	17			
TS_0.8mm	**Between Groups**	366,663	2	183,331	,358	,705
	Within Groups	7682,247	15	512,150		
	Total	8048,910	17			
YS_3mm	**Between Groups**	98,015	2	49,007	1,076	,366
	Within Groups	683,224	15	45,548		
	Total	781,238	17			
YS_2mm	**Between Groups**	192,539	2	96,269	,995	,393
	Within Groups	1451,025	15	96,735		
	Total	1643,564	17			
YS_0.8mm	**Between Groups**	1971,627	2	985,814	2,505	,115
	Within Groups	5904,117	15	393,608		
	Total	7875,744	17			

IV. Conclusion

Some measured properties of steel that must be considered when designing a cold formed steel structure include tensile strength, yield strength and modulus of elasticity. All of these parameters can be determined by tensile test. In the present study, it is intended to determine the most favorable method for preparing tension test specimen for design of cold formed steel member. For this purpose, series of tension tests are carried out on three different cutting methods with three different thicknesses. Selected cutting methods are laser cutting with oxygen, laser cutting with nitrogen and wire electrical discharge machine cutting. Selected steel sheet thicknesses are 0.80mm, 2.00mm and 3.00mm, respectively. Purpose of selecting different cutting methods on different thicknesses is examined heat effects and different textures at cutting surface on the test specimen.

(a)
(b)
(c)

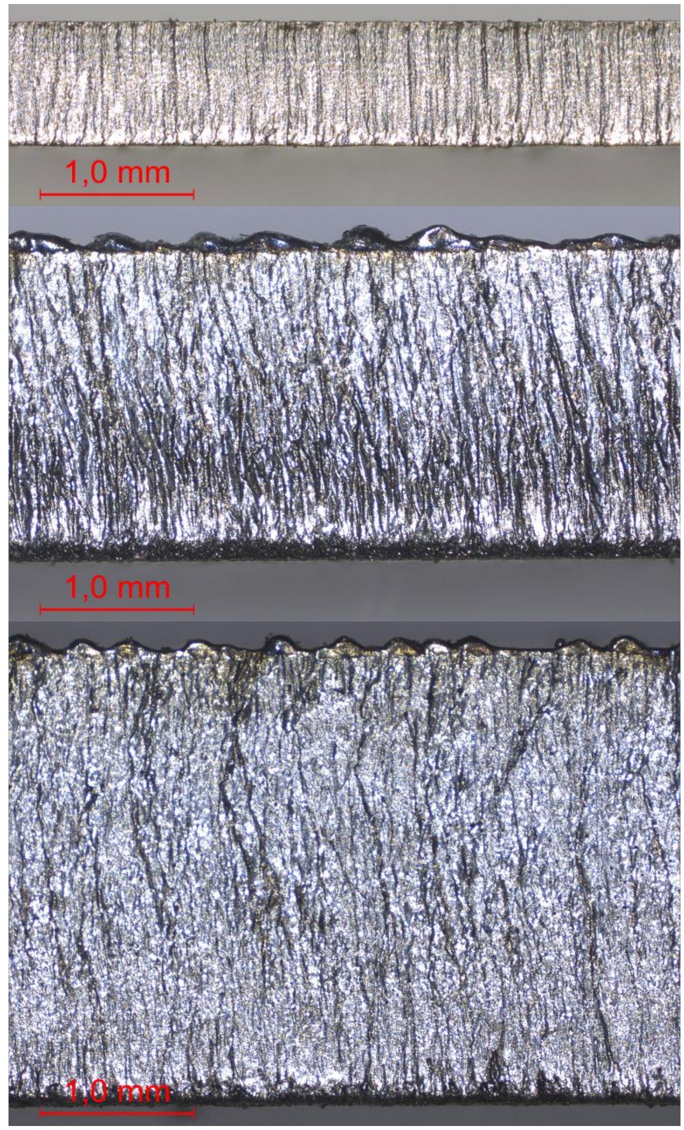


Figure 4. Cutting surfaces for laser cutting with nitrogen (a) 0.032" (0.8mm) (b) 0.078" (2.0mm) (c) 0.118" (3mm)

Examination of different textures on cutting surfaces is carried out motorized 16:1 macroscope with high resolution equipment. Methods compared with three different roughness, waviness and form parameters. Each cutting method surface texture reveals a specific form of unevenness. Wire electrical discharge machine quilting has most uniform and favorable texture among these three methods.

For determination of heat effects on the tension test specimen, 54 tension test specimens were manufactured and tested with regard to ASTM E8/E8M-11 standard. Wire electrical discharge machine cutting process is preparing specimen while it's submerged into water. For this reason, expected most favorable cutting method is wire electrical discharge machine cutting. Second expected favorable method is laser cutting with nitrogen, because of nitrogen gases cooling effect. But ANOVA analysis shows that there is no significant difference with 95% confidence level between three cutting methods for three different thicknesses.

For all reasons above, the most favorable method will be proposed from time and cost criteria. In this case, the least advantageous method is wire electrical discharge machine cutting. The cutting process consumes too much time and also cost. Laser cutting with nitrogen and oxygen is almost consumes same time process time and cannot compare with wire electrical discharge process time. As a consequence, laser cutting with oxygen can be preferable because of it's slightly cheaper than Laser cutting with nitrogen.

(a)
(b)
(c)

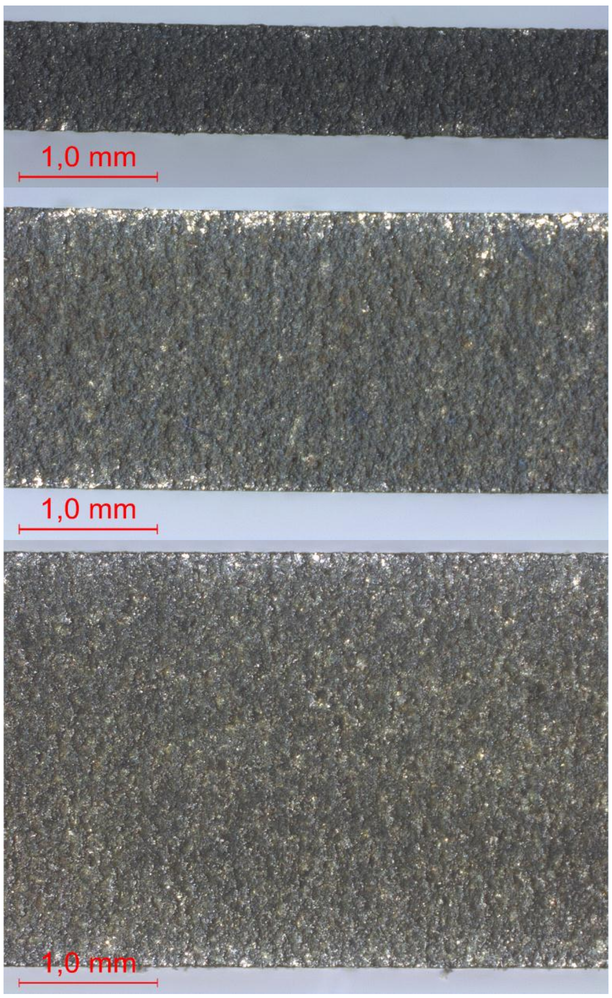


Figure 5. Cutting surfaces for wire electrical discharge machine cutting (a) 0.032" (0.8mm) (b) 0.078" (2.0mm) (c) 0.118" (3mm)

(a)
(b)
(c)

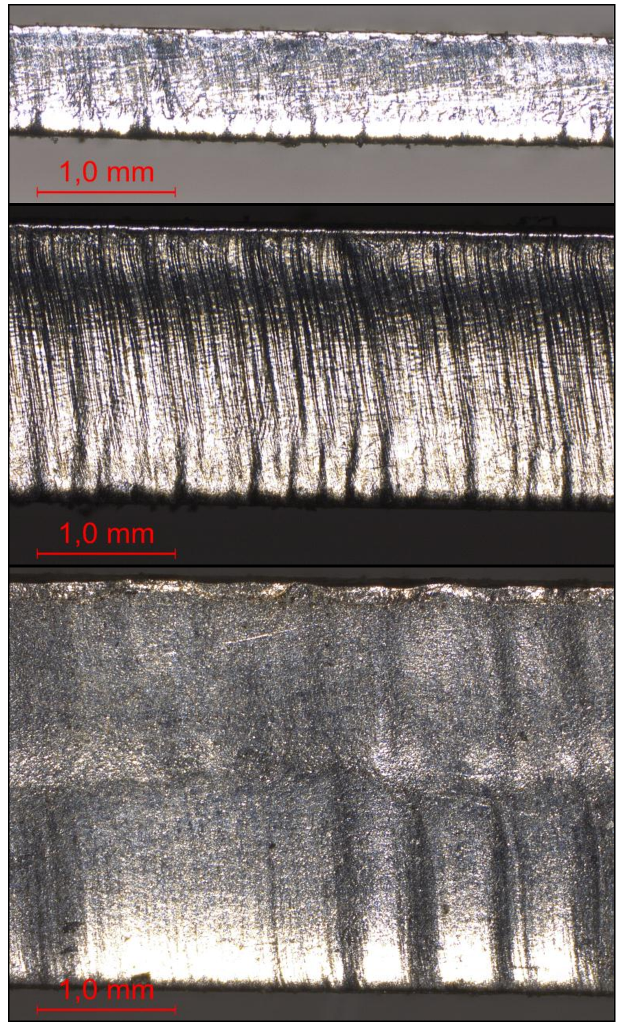


Figure 6. Cutting surfaces for laser cutting with oxygen (a) 0.032" (0.8mm) (b) 0.078" (2.0mm) (c) 0.118" (3mm)

Acknowledgment

Authors gratefully acknowledge the financial assistance of the Scientific Research Projects Unit of the University of Gaziantep provided under Project: RM.10.04.

References

[1] ASTM StandardE8/E8M, Standard Test Methods For Tension Testing of Metallic Materials, ASTM International,2011.

[2] R.K. Boger, R.H. Wagoner, F. Barlar, M.G. Lee, K.Chung ''Continuous ,large strain ,tension / compression testing of sheet material'' in International journal of Plasticity, 2004.

[3] Davis, J.R., Tensile Testing, ASTM International.,2004

[4] Forsman, A. C., Lundgren, E.H., Dodell,. A.L. and Komashko, A.M. ''A Nanosecond Pulse Format in Lazer Drilling'' General Atomics,2007.

[5] Geels, K.,''Metallographic and Materialographic Specimen Preparation, Light Microscopy, Image Analysis and Hardness Testing'', ASTM International.2006

[6] Loveday, M.S., Gray, T. and Aegerter, J.''Tensile Testing of Metallic Materials'',Review, Project report.2004.

J.R. Townsend and W.A. Straw ,''Physical Properties and Methods of Test for some Sheet Non-Ferrous Metals.