EFFECT OF WELDING STRESSES INDUCED BY HAZ ON THE WELDMENT TOUGHNESS +

تأثير أجهادات اللحام المتولــدة في المنطقة المتأثرة بالحرارة على متانة الملحــومات

Abdul-Wahab Hassan Khuder* **Sabah Khammass Hussein** *

Abstract:

The aim of this work is to study the effect of welding stresses induced by heat affected zone (HAZ) on the weldment toughness. Two types of welding electrode (AWS E6010& AWS E6013) are used to weld the specimen. In which the notch is machined at the weld metal for the specimen at the HAZ (x=0.0 mm), (x=5 mm) and (x=10mm) at region near the base metal measured from the center of specimen. The welding operation is achieved at three values of currents for each electrode type, such that the current values are (I=70, 80 & 90Amp.).

The results indicated that for the weldment tested for type (E6010), the impact energy increase gradually during increasing the current, and for type (E6013), the energy decrease gradually with current. That means the current has an effect on the stress on the weld mental. The results also illustrate that the increasing in the stresses was found in the higher current in the welding wire (E6010) as comparing with (E6013) for all values of the welding distance (x).

المستخلص:

يهدف البحث إلى دراسة تأثير أجهادات اللحام المتولدة في المنطقة المتأثرة بالحرارة على متانة الملحومــات. تــم استخدام نوعين من أسلاك اللحام (E6010 & E6013) لغرض لحام عينات الصدمة ، حيث تم عمل حز في العينات في المنطقة المتأثرة بالحرارة للمسافات (x=0.0 mm)، (x=5 mm) و (x=10mm) وفي المنطقة القريبــة مــن المعدن الأساس مقاسه من مركز العينة . عملية اللحام أجريت لثلاثة قيم من التيار ولكل نوع من أسلاك اللحام، حيث كانت قيم التيار (I=70, 80, 90 أمبير) .

أشارت النتائج الى أن طاقة الصدمة تزداد مع زيادة التيار للملحومات ذات سلك اللحام (E6010) وتقل لتلك الملحومات ذات سلك اللحام (E6013). وهذا دليل على أن التيار له تأثير على توزيع الأجهادات في المعدن الملحوم . كذلك أشارت النتائج الى أن أجهادات اللحام تزداد بالنسبة للتيارات العالية للملحومة ذات سلك اللحام (E6010) مقارنة مع تلك الملحومات ذات سلك اللحام (E6013) لكل قيمة من المسافة (x).

Introduction:

The development and production of High Strength Low Alloy (HSLA) pipe line steels has been growing rapidly because of their desirable combination of high strength, low temperature toughness, weldability and low cost. With the advent of the welding as the major

+ **Received on 10/11/2011 , Accepted on 20/7/2011 .**

* **Lecturer /Technical College-Baghdad**

method of fabrication, cracking in the heat affected zone has become a serious problem particularly in large and continuous structures. One of the major problems in the welding of steels has been the type of cracking generally known as hydrogen induced cold cracking [1].

At high carbon levels, the heat affected zone cracking was severe because of the formation of brittle martensite as a result of rapid cooling in welding. In the presence of hydrogen gross cracking was inevitable. Recognizing the deleterious effect on notch toughness and weld ability by carbon in welding, the trend towards newly improved materials has resulted in the development of lower carbon steels. Quenched and tempered steels were produced using alloy elements such as manganese and silicon as the main strengtheners in solid solution. These additives increased the hardenability of the steels to make heat treatments possible. With the concurrent development of low hydrogen electrodes, these steels were easily welded without any cracking problem at least in thin section. In general preheat is only required in thicker section and when the restraint is high. However, since mechanical properties of these steels were strictly controlled by careful heat treatments during processing, the thermal cycle in welding can significantly impair strength and toughness in the fusion zone and the heat affected zone. This limitation in the use of quenched and tempered steels has paved the way for developing lower cost, high strength and toughness low alloy steels. There are five major factors determining the strength, impact toughness and weld ability of low alloy steels. They are carbon content, dislocation density, precipitation hardening, solid solution hardening and grain size. Both strength and toughness; the other strengthening mechanisms improve strength at the expense of toughness [2].

Hammer-peening the last weld layer confines tensile residual stress inside the weld, while inducing compressive stress at the weld surface. Charpy test results show that the better toughness and comparable cavitations erosion resistance [3].

The FEM used to determine the values of residual stress in weldments based on the estimation of eginstrain. It concluded that this method is a useful for the comparison of residual stress measurement method [4].

Hot cracking of welds is an important problem in the welding industry. It is thought to occur in a temperature range that begins at the start of solidification and ends soon after solidification is entirely complete.

During the later stage of solidification, there exists a brittle temperature range in which the strength and ductility of the alloy are very low as some low melting-point constituents segregate between dendrites and form liquid films. At the same time, stresses/strains arise from solidification shrinkage, thermal contraction of parent metal and external restrains.

Like many other cracking problems, solidification cracking occurs when the mechanical driving force exceeds the material resistance to cracking. This concept is illustrated by figure (1) [1].

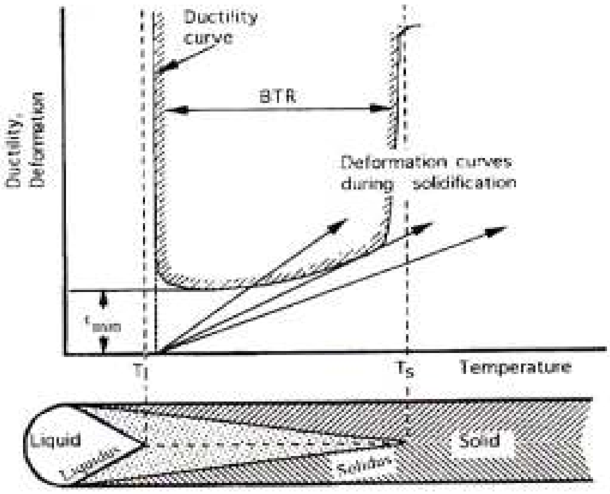

Figure (1) The material resistance versus mechanical driving force concept [1].

Hot cracking is observed to be sensitive to chemical composition. It is thought that a critical strain and critical strain rate exists. As the strain rate is decreased, the critical strain decreases but below a critical strain rate, hot cracking dose not occurs [2].

In plain carbon steel structure, it has long been recognized that brittle fractures almost never propagate along the heat affected zone (HAZ) of welds; consequently little effort was made to measure the toughness of the HAZ. However, with the increasing use of medium and high strength steel and the development of high heat welding processes, the toughness of the HAZ was questioned and a number of papers were published on the subject [5].

Experimental Work:
Materials Selection:

The material used in fabricate the impact test specimen is carbon steel with a square section (10*10*55) mm, and the chemical composition is shown in table (1).the weld metal of the electrode is of type (E6010& E6013) according to the American welding society (AWS).

Table (1) Chemical composition of the Carbon steel used.

Bar Materials	Composition wt %										
	C	Si	P	S	Cr	Mo	Ni	Mn	Cu	V	Fe
DIN Ck 65	0.650	0.260	0.015	0.030	0.115	0.008	0.053	0.947	0.037	0.004	Rem.

Preparation of Welding and Impact Test Specimens:

A standard square bar of impact specimen (Charpy test) is cut with a dimensions (10*10*55) mm .Divide the square bar specimen into two halves for welding purposes, Then fixing the two halves specimen by catching as shown in the figure (2). The required distance between the two edges must be (0.3) mm according to the welding specification of design welding. Weld the specimen with a suitable electrode wire is (E6010& E6013), which gives good welding joint with carbon steel used .The welding process of joint is achieved with three passes. Then after each pass cleaning the welding joint with brushing to remove the slag and prevent porosity, and facing the welding zone to alignment with the base metal.

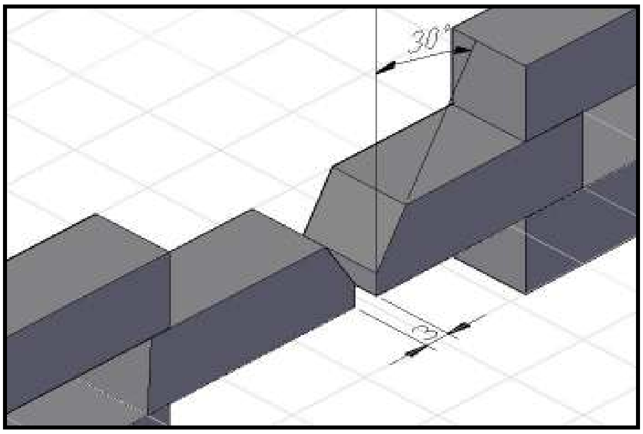

Figure (2) Preparation and fixing the two halves specimen to welding.

Notch Designation:

The notches in the specimen facilitate the impact test. The description of the notch is as follow:-
1. The depth of notch is (2 mm) as shown in figure (3).
2. It must be in the middle of the specimen.
3. The shape of the notch as (V) made with milling machine with cutters of (45°).

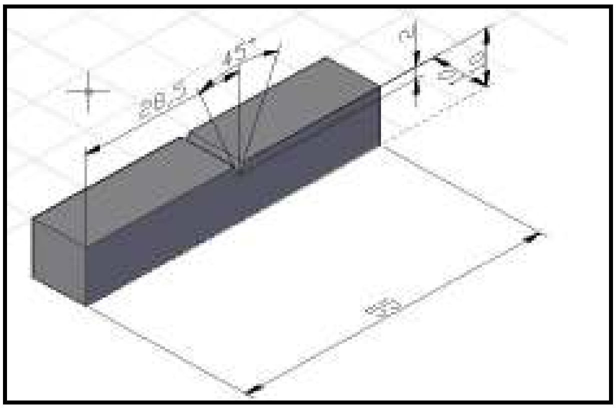

Figure (3) The notch dimension, all dimensions in (mm).

Weldment Specimen:

The tested specimens include the base material impact specimen of carbon steel and the welding specimen (welded according to American welding society [6]) which classified as follows:

1. Test the weldment specimen in the weldment region, figure (4a).
2. Test the weldment specimen at x=5mm, in which the effects of HAZ are diminished, figure (4b).
3. Test the weldment specimen at x=10mm, in which the effects of HAZ are diminished, figure (4c).

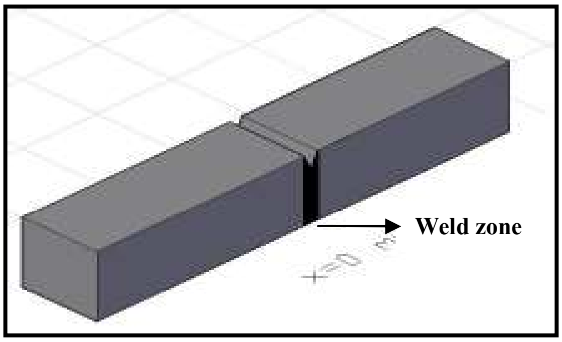

Figure (4a)

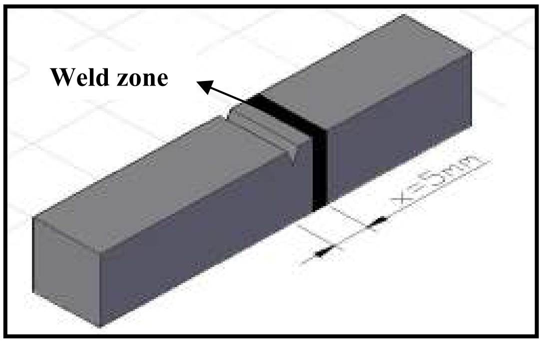

Figure (4b)

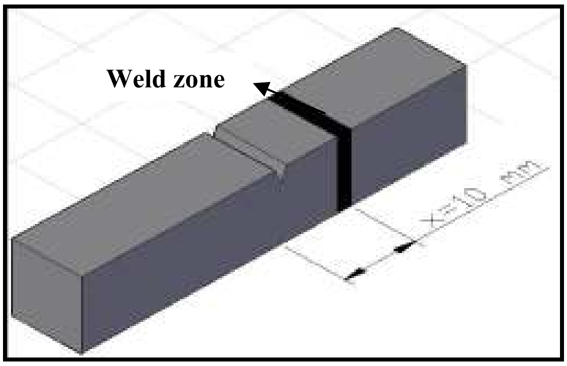

Figure (4c)

Impact Toughness Experiment:

Notch toughness is the ability of a material to absorb energy in the presence of a flaw. As mentioned previously, in the presence of a flaw, such as a notch or crack, a material will likely exhibit a lower level of toughness. When a flaw is present in a material, loading induces a triaxial tension stress state adjacent to the flaw. The material develops plastic strains as the yield stress is exceeded in the region near, it fails the crack tip. However, the amount of plastic deformation is restricted by the surrounding material, which remains elastic [7].Figure (5), shows the impact test equipment used in this work.

Figure (5) Impact Test Equipment used in this work.

Results and Discussion:

The results of experimental tests for the three types of weldment tested in impact equipment with x = 0, 5 and 10 mm, with type of welding electrode (E6010 & E6013) has been listed in table (2) .It shown the minimum energy is appear at the heat affected zone (x=5 mm) for the type of electrode (E6010) with minimum current (70 Amp.) and reach the maximum value for the same type of electrode and the same value of (x=5mm)at the energy equal to (235) and the current equal to (90 Amp.).

Table (2) Charpy Number for the impact weldment specimen.

Type of Electrode	Current (Amp.)	x (mm)	Charpy Number
E6010	70	0	50
E6010	70	5	32
E6010	70	10	152
E6010	80	0	122
E6010	80	5	180
E6010	80	10	210
E6010	90	0	55
E6010	90	5	235
E6010	90	10	170
E6013	70	0	70
E6013	70	5	58
E6013	70	10	206
E6013	80	0	55
E6013	80	5	50
E6013	80	10	182
E6013	90	0	58
E6013	90	5	193
E6013	90	10	126

The weldment of impact tests specimen has been tested under the impact equipment. Figures (6) - (8) represents the effect of weldment and displacement, HAZ and the stress on the energy found from the impact test during the change of current. It has been shown from figure (6) that the energy increases with increasing current for wire (E6010) and decrease at current (90 Amp). The maximum energy is found at (80Amp.) and the minimum energy found at current (90Amp.). For type (E6013), the energy reduces gradually with current. That means the current has an effect on the tensile distribution on the weld metal.

Figure (8) represent the effect of stress on the HAZ as approximate value at (x=5mm) the energy increase gradually during increasing the current and the values of energy for type (E6010) gives maximum values as comparing with the other type (E6013) especially at higher current that means the cracking in the heat affected zone decrease will be small in type (E6010) as comparing with that in (E6013) and the tensile stress in the HAZ will be small in the weldment which welded with type (E6010) as comparing with that in (E6013) or the compression stress will be large in (E6010) than that in type (E6013) weldment type. Figure (8) is weldment of type (E6010) gives a higher energy as comparing with that in (E6013) and the variation of current will affect on the changing of stress in the specimen at (x=10mm). An optimum value has been shown at the current (80Amp) with the weldment of type (E6010).

On the other hand to study the effect of the stresses resulted from the weldment on the distance (x); figure (9-11) shows this effect. The current (70Amp) gives a higher energy at the impact specimen for type (E6013) for all values of (x) as shown in figure (9).That means, the compression stress will increase and the tensile stress will decrease in the type of (E6013) weldment as comparing of (E6010) for the region of weld metal . Figure (10) shows that the welding with current (I=80Amp.) gives a good energy values for type (E6010) weldment than that with (E6013). The same result has been shown in figure (11) and the maximum energy was found at (x=5mm) HAZ for the current (90Amp).

Hence the increasing in compression stress and the decreasing in the tensile stress was found in the current (80&90Amp.) in the welding wire (E6010) as comparing with that of (E6013).

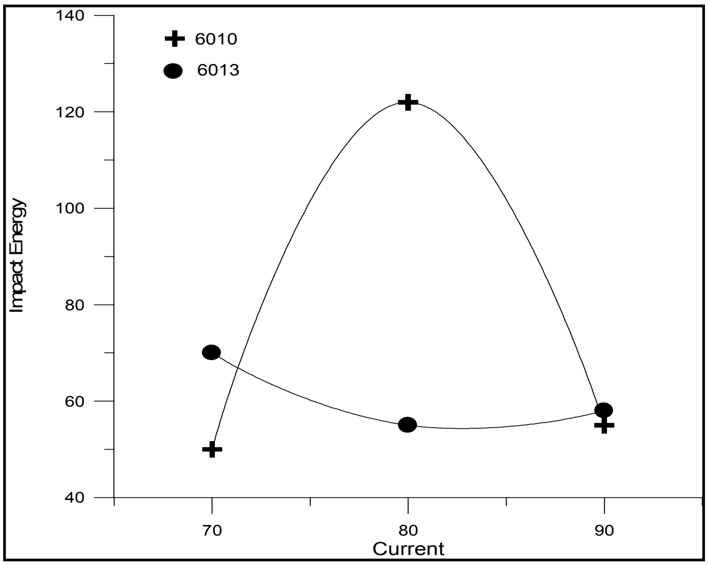

Figure (6) Effect of current at x= 0 mm.

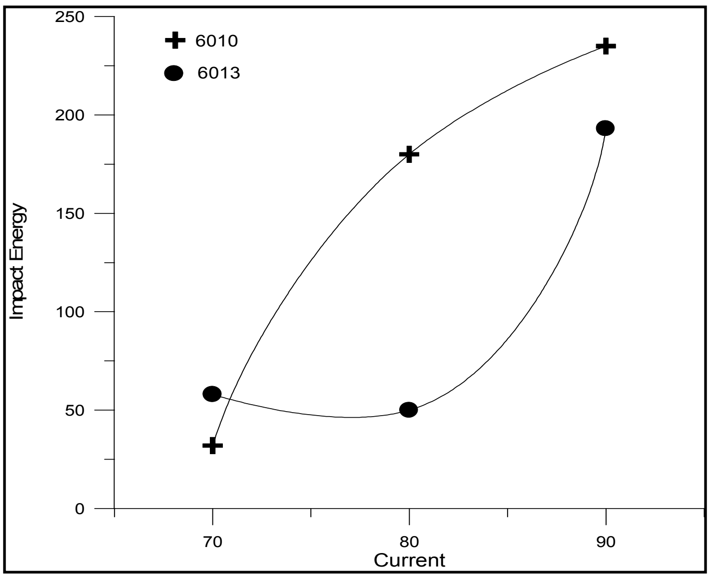

Figure (7) Effect of current at x= 5 mm.

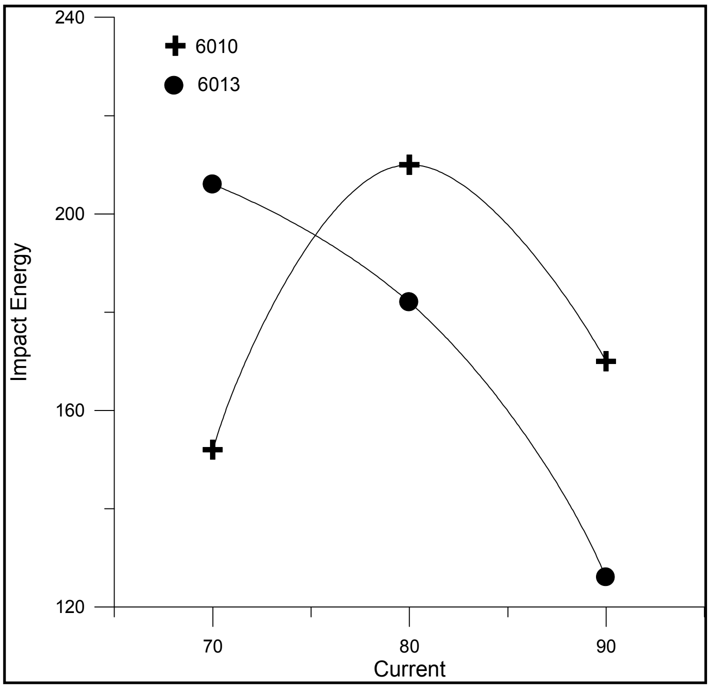

Figure (8) Effect of current at x= 10mm

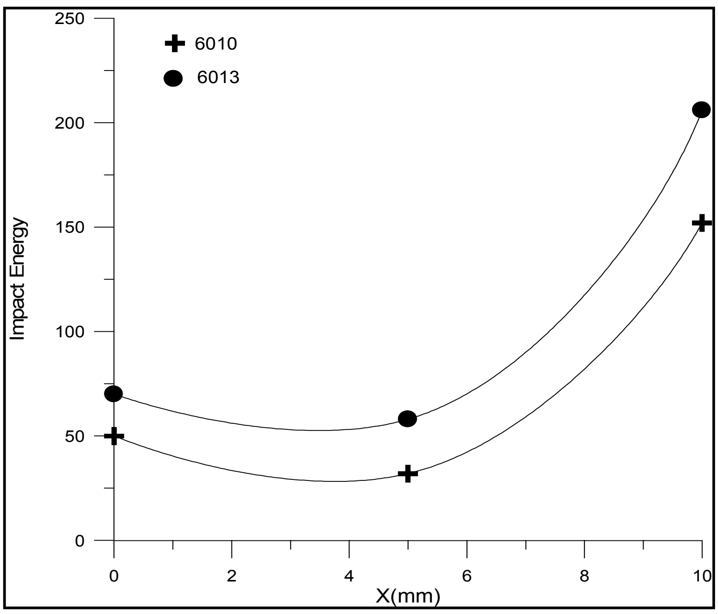

Figure (9) Effect of weld metal at I= 70 Amp.

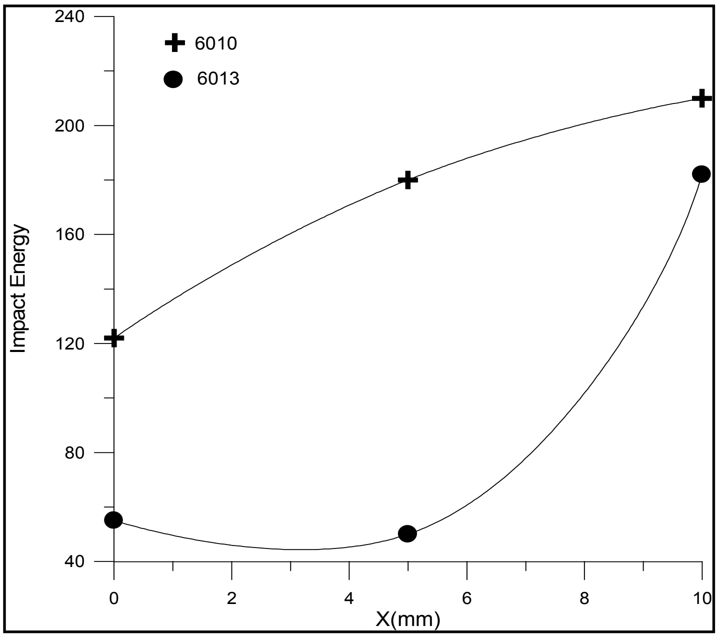

Figure (10) Effect of weld metal at I= 80 Amp.

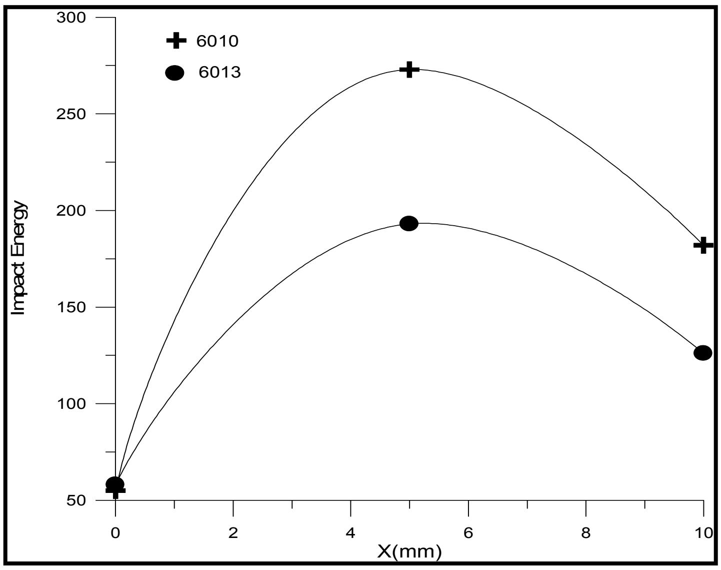

Figure (11) Effect of weld metal at I= 90 Amp.

Approaches models can be estimated from the above figures using a curve fitting method to represent the relations between the impact energy and the welding line distance as follows, table (3):

Where:
Y: Impact Energy.
X: Distance between the welding line and the center of impact specimen.

Table (3) Modeling of Impact Energy.

Current	Figure	Welding Filler Type	Impact Energy Equation
70	10	E6010	$Y=78+25.5X+17.25X^2$
70	10	E6013	$Y=111.33+34X+20X^2$
80	11	E6010	$Y=170.66+22X-3.5X^2$
80	11	E6013	$Y=95.66+31.75X+17.125X^2$
90	12	E6010	$Y=153.33+28.75X-30.625X^2$
90	12	E6013	$Y=125.6666+17X-25.252X^2$

Conclusion:

The following are the most notable conclusion can be summarized as follows:

1. The minimum energy is appear at the heat affected zone (x=5 mm) for type of electrode (E6010) with minimum current (70 Amp.) and reach the maximum value for the current equal to (90 Amp.). For type (E6013), the energy reduces gradually with current. That means the current has an effect on the tensile distribution on the weld metal.
2. The energy increase gradually during increasing the current for type (E6010) as comparing with the other type (E6013) and the optimum value has been shown at the current (80Amp.), that means the cracking in the heat affected zone decrease will be small in type (E6010) as comparing with that in (E6013).
3. The tensile stress in the HAZ will be small in the weldment which welded with type (E6010) as comparing with (E6013) or the compression stress will be large in (E6010) than (E6013), for the region of weld metal. The maximum energy was found at (x=5mm) HAZ for the current (90Amp).
4. The increasing in compression stress and the decreasing in the tensile stress was found in the current (80&90Amp.) in the welding wire (E6010) as comparing with that of (E6013).
5. Approaches models can be estimated and represent the relations between the impact energy and the distance between the welding line and the center of impact specimens.

References:

1. J. A. Goldak, M. Akhlaghi "*Computional Welding Mechanics*" Springer Science Business Media, Inc, 2005.
2. T. Bollinghaus "*Hot Cracking Phenomena in Welds*", Springer-Verlag Berlin Heidelberg 2005.
3. R. Simoneau, D. Thibault, J. L. Fihey, "*A comparison of Residual Stress in Hammer Peened Multipass Steel Welds",* International Institute of Welding for the General Assembly of Graz, 6-11 July 2008.
4. M. R. Hill," *Determination of Residual Stress Based on the Estimation of Eigenstrain*", Ph.D. thesis, Stanford University, Mechanical Eengineering, 1996.
5. Andrzej Słuzalec, "*Theory of Thermo-mechanical Processes in Welding*", Springer, 2005.

6. American Welding Society, "*Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding",* 1999.
7. D. R. Askeland, P. P. Phule "*The Science and Engineering of Materials*", Thomson Brooks Cole, 2004.