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Impact Energy of Weld Metal in CK45 Carbon Steel

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ABSTRACT

Due to high joint efficiency, welding is widely used to join materials. Today, there are many types of welding procedures in different manufacturing industries. Among welding procedures, Gas Metal Arc Welding (GMAW) is a versatile process due to its high flexibility. In this process, arc voltage, welding current, and welding speed are the main variables which can strongly affect the mechanical properties of the weld metal. Based on the available literature, many research works have been conducted on the GMAW process but there is still little experimental research on impact energy of the weld metal specifically in medium-carbon steels. Impact energy of the weld metal is extremely important particulary for the structures subjected to impact loads. Hence, the present paper is conducted to reveal the effect of GMAW variables on impact energy of the weld metal in CK45 carbon steel. The results of this paper indicated that the heat input value and weld bead size in different welding conditions are main factors which affect the impact energy of the weld metal.

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INTRODUCTION

Welding is an important process commonly used to join the different materials together [1]. Numerous metallic materials can be joined using various welding methods, including friction stir welding (FSW), friction stir spot welding (FSSW), ultrasonic welding (USW), gas tungsten arc welding (GTAW), laser beam welding (LBW), gas metal arc welding (GMAW), and arc stud welding (ASW). All of these methods have different advantages and disadvantages in terms of cost, appropriateness, labor, training, efficiency, time, temperature, and simplicity [2–7]. There are five mechanization and automation levels stated in welding: (1) manual (2) semi-automatic (3) mechanized (4) automatic, and (5) robotic. The robotic welding process has more advantages than the conventional manual process, such as that the quality of the weld is more consistent, the process speed is higher compared with manual, there is less waste, and a reduced cost [8].

The GMAW is a conventional liquid-state welding process for mass production allowing high welding speed, deep penetration, and high deposition rate; resulting in an attractive process for assembling large components [9]. In GMAW, an electric arc forms between the welding electrode and the base metal. The electric arc which is being formed melts the metals and makes them melt so that they are joined together. The GMAW is known as the Metal Inert Gas (MIG) welding or Metal Active Gas (MAG) welding [10–12]. This process is an important procedure in various industries such as shipbuilding, aircraft, aerospace, building construction, pipeline system, and automotive industry [13]. From what we know, welding processes parameters can have important and significant influences on mechanical properties of the weld metals. Thus, a wide range of mechanical properties can be developed for the weld metals produced by GMAW due to a lots of welding variables in this process.

Among iron-carbon alloys, carbon steel is one of the most widely used materials in the industry for the moderate and service requirements [14]. Carbon is the most important alloying element in carbon steel which affects its mechanical properties. Typically, increasing carbon content increases hardness and strength and decreases ductility and formability of steel. Depending on carbon content, carbon steels are divided into three main groups: (i) low-carbon steels (ii) medium-carbon steels, and (iii) high-carbon steels. Medium-carbon steels contain carbon from 0.3% to 0.6% and manganese from 0.6% to 1.65%. These steels are mainly used for making shafts, axles, gears, crankshafts, couplings, and forgings. Steels with carbon ranging from 0.4% to 0.6% are used for rails, railway wheels, and rail axles [15]. Due to their high applications, it is important to know the behavior of medium-carbon steels during the welding process. The CK45 medium-carbon steel (according to DIN 1.1191 standard) is widely applied in various industries, including car and engine parts, parts such as bushes and crankshafts, and industrial shafts and rollers. Also, due to the low cost, it is sometimes used to fabricate the pumps shaft.

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Physically, energy is a quantitative property and measurable in metals and materials. It can be transferred to other objects and converted into different states and forms. Besides, energy is a fundamental property to describe the state of a particle, object, or system. In many references, energy is defined as the ability to perform work. Depending on how it is released and affected, there are many different types of energy, including thermal energy, chemical energy, electrical energy, nuclear energy, and etc. A famous type of energy is impact energy. The energy required to fracture a standard test specimen is known as impact energy which is usually measured by impact testing. The impact energy of the weld metal is an important property specially for structures subjected to impact or sudden loads like structure of a vehicle at the moment of the accident which require a high safety factor. Impact test specimen types include notch configurations such as V-notch, U-notch, and keyhole notch. Impact testing most commonly consists of Charpy and Izod specimen configurations [16]. Considering the above cases, this study focuses on effects of GMAW process parameters including welding current, arc voltage, and welding speed on impact energy of the weld metal in CK45 carbon steel.

MATERIALS AND METHODS

In this study, due to high industrial importance, the CK45 carbon steel in the form of plate with 10 mm thickness was used as base material. The plates were beveled at 30° angle to provide single-V-groove butt joints configurations with 60° groove angle. The preparation operation of base material is illustrated in Figure 1. To prevent distortion, the plates were located in the jig fixtures before the welding process.

The GMAW welding operations in this study were carried out using a SOS Model DR Series ARK ROBO 1500 welding robot with capacity of 0-600 A and 0-50 V ranges. The welding robot and its apparatus are illustrated in Figure 2. A multiple-pass welding technique was used to join the base materials, and the molten weld pool was protected with 100% CO_2 shielding gas. The ER70S-6 (AWS A5.18 Classification) wire electrode having 1 mm diameter with composition of 0.11C-1.63Mn-0.95Si-0.5Cu (wt. %) was used as filling metal. The welding current, arc voltage, and welding speed were chosen as research variables, and all other variables were fixed.

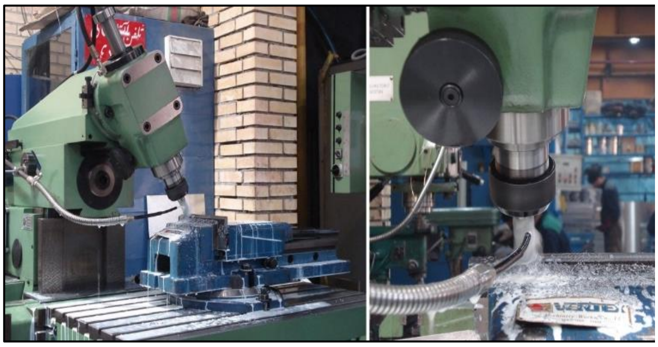

Figure 1. The preparative operation of base material used in this study

Figure 2. The welding robot and its auxiliary equipements used in this study

In this paper, the Charpy impact testing was used to measure the impact energy of the weld metals. Having finished the welding operations, the standard Charpy V-notch (CVN) specimens with dimension of 55 mm × 10 mm × 10 mm were extracted from the welded joints. The specimens contained a 45º V-notch, 2 mm deep with a 0.25 mm root radius, and the notch was located in the center of the specimens and weld metals and parallel to the direction of weld line in specimens. Impact tests were carried out at 25 ºC by a Dynatup KGH 8250 at an impact velocity of 5.25 m/s and a tup capacity of 44.5 kN. Some of standard impact test specimens and the base of the test are illustrated in Figure 3.

RESULTS AND DISCUSSION

The Charpy impact test results for the weld metals produced in different welding conditions are listed in Table 1. As shown, the Charpy impact energy of the weld metals varied from 89.21 J to 154.25 J with changing in parameters of GMAW process. The minimum impact energy value of 89.21 J was obtained at the highest welding current and arc voltage, and the lowest welding speed in this study (120 A, 27 V, and 42 cm/min). The maximum impact energy value of 154.25 J was obtained at welding current of 110 A, arc voltage of 23 V, and welding speed of 62 cm/min.

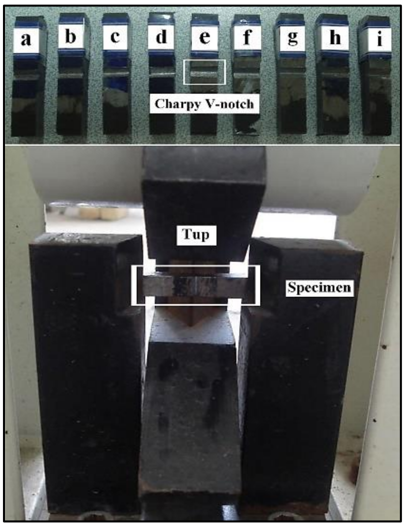

Figure 3. Some of the Charpy impact test specimens and base of impact testing

TABLE 1. Charpy impact test results for the weld metals produced in different welding conditions

Welding Conditions	**Number**	**I (A)**	**V (V)**	**S (cm/min)**	**Impact Energy (J)**
Set One	1	100	23	42	130.11
	2	100	23	62	140.93
	3	100	23	82	118.71
	4	100	25	42	125.41
	5	100	25	62	146.90
	6	100	25	82	120.18
	7	100	27	42	115.25
	8	100	27	62	153.21
	9	100	27	82	126.12
Set Two	1	110	23	42	124.51
	2	110	23	62	154.25
	3	110	23	82	125.43
	4	110	25	42	113.10
	5	110	25	62	148.73
	6	110	25	82	132.77
	7	110	27	42	108.87
	8	110	27	62	138.71
	9	110	27	82	137.85
Set Three	1	120	23	42	109.13
	2	120	23	62	139.76
	3	120	23	82	135.68
	4	120	25	42	96.50
	5	120	25	62	132.51
	6	120	25	82	140.40
	7	120	27	42	89.21
	8	120	27	62	132.05
	9	120	27	82	144.41

Welding heat input has a enormous influence on mechanical properties of the weld metal. Heat input calculations are used extensively in the welding industry, and the accurate calculation of these values is of utmost importance [17]. Associated to the weld quality, the weld bead geometry is one of the most important parameters in welding processes. It is a significant requirement in a welding project, especially in automatic welding systems [18]. Hence, in order to study the effect of GMAW process parameters on impact energy of the weld metal in this study, much of the discussion was focused on heat input values and weld beads size, and theirs effect on impact energy of the weld metals. The heat input values calculated from Equation (1) [19] for different welding conditions are illustrated in Figure 4. As shown, The heat input value increases with increasing welding current or arc voltage; but, welding speed has a reverse effect on heat input value. Increasing the welding speed decreases the heat input value, and these behaviors are observed for all conditions in this study. As demonstrated in this work, increasing the welding current or arc voltage increases the heat input value, but increasing the welding speed decreases its value. The maximum heat input value for welding current of 100, 110, and 120 A was 385.7, 424.3, and 462.9 J/mm, respectivly which were obtained at arc voltage of 27 V and welding speed of 42 cm/min. Welding heat input in this study varied from 168.3 J/mm to 462.9 J/mm with changing in GMAW process parameters. As shown in Figure 5, the total range of the impact energy changes was from 89.21 J to 154.25 J with varing the heat input value from 168.3 J/mm to 462.9 J/mm. The impact energy of the weld metal increased from 118.71 J to 154.25 J when the heat input value was increased from 168.3 J/mm to 244.8 J/mm. Then it decreased to 89.21 J with further increasing the heat input to 462.9 J/mm.

As the weld bead size increases, which corresponds to a higher heat input, the notch toughness tends to decrease. This means that the weld bead size has a negative effect on notch toughness. In multiple-pass welds, the heat from each pass tempers the weld metals below it. Also, heat input due to each pass increases internal energy of the previous weld passes.

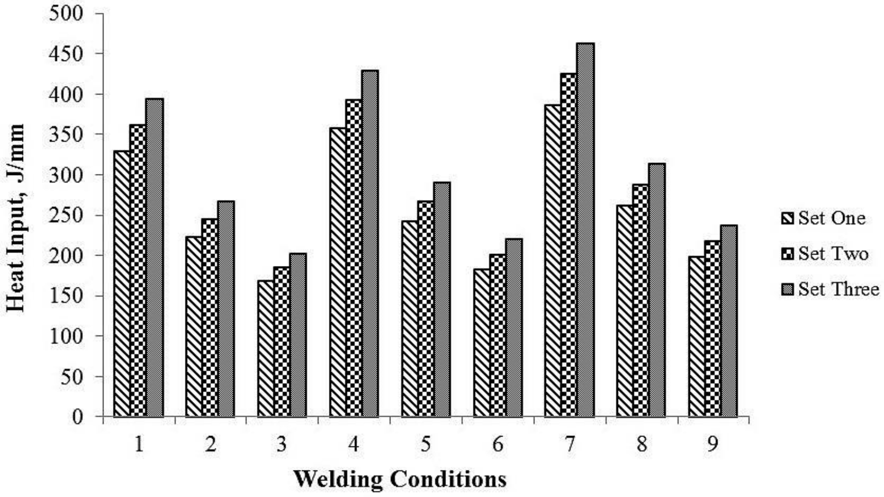

Figure 4. The heat input values calculated for welding conditions set one, two and three

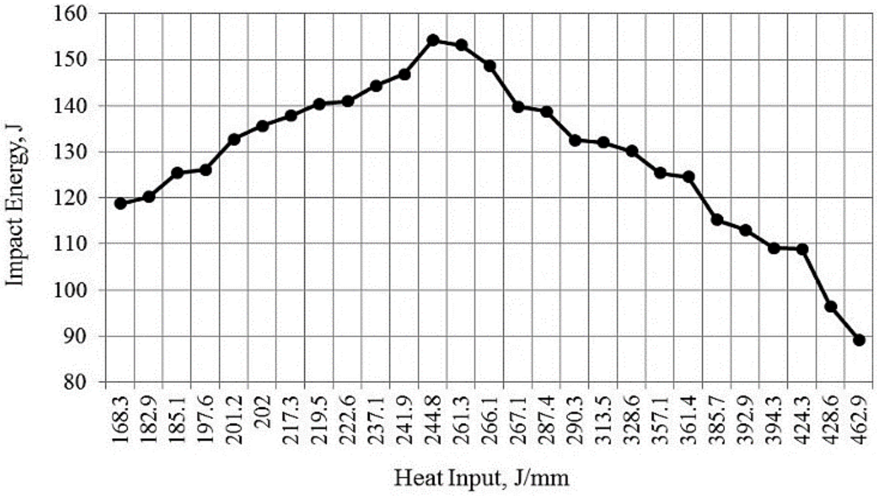

Figure 5. The total range of impact energy values of the weld metals vs. heat input values

Thus, a portion of the previous weld passes is refined, and the toughness improved. If the weld beads are smaller, more grain refinement occurs, resulting in better notch toughness, all other factors being even [19]. Although, the weld bead size increased with increasing heat input, but it seems that these increases in weld bead size were not significant and remarkable and weld beads were still small when heat input was increased from 168.3 J/mm to 244.8 J/mm. Therefore, weld bead size was not a dominant and determinant factor in determining the impact energy value of the weld metal, and its effect was negligible. In this condition, impact energy of the weld metal started to increase due to: (i) further increases of internal energy (ii) more temperings (iii) more and stronger refinements (iv) greater improvements in notch toughness, in previous weld passes.

But weld beads became too large, and the increases in their size were significant and remarkable when heat input was increased above 244.8 J/mm. The effect of weld bead size on impact energy of weld metal was stronger than effects of other factors in this condition, and the impact energy of the weld metal started to decrease.

$$H = \frac{60.I.V}{1000.S} \tag{1}$$

where, H is heat input (kJ/mm), V is the arc voltage (V), I is welding current (A), and S is welding speed (mm/min).

CONCLUSIONS

As a quantitative and measurable property in metals and materials, energy is a fundamental characteristic to describe the state of particles, objects, or systems. Depending on how it is released and affected, there are many different types of energy in which a famous type of energy is the impact energy. The impact energy of the weld metal is an important property specially for structures subjected to impact or sudden loads. Hence, the impact energy of weld metal in CK45 carbon steel was investigated in this study. According to the obtained results from this study:

(1) The various values of heat input were obtained by the change of GMAW process parameters. Increasing welding current or arc voltage increased the heat input

value, while increasing welding speed decreased its value .

(2) The heat input values in this study varied from 168.3 J/mm to 462.9 J/mm with changing in GMAW process parameters. The highest heat input value of 462.9 J/mm was obtained at welding current of 120 A, arc voltage of 27 V, and welding speed of 42 cm/min .

(3) The Charpy impact energy of the weld metals varied from 89.21 J to 154.25 J with changing in parameters of GMAW process .

(4) When heat input was increased from 168.3 J/mm to 244.8 J/mm, the impact energy of the weld metal increased, and then dropped with further increasing heat input from 244.8 J/mm to 462.9 J/mm. The maximum impact energy value of 154.25 J was obtained for the weld metal produced at arc voltage of 23 V, welding current of 110 A, and welding speed of 62 cm/min.

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Persian Abstract

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چکیده

فرایند جوشکاری به جهت کارایی بالا در اتصال‌دهی، به طور گسترده جهت اتصال مواد مختلف مورد استفاده قرار می‌گیرد. امروزه، انواع مختلف روش‌های جوشکاری در صنایع گوناگون تولید مشاهده می‌شوند. در بین روش‌های جوشکاری، فرایند جوشکاری قوسی با گاز محافظ به علت انعطاف‌پذیری بالا، یک فرایند همه‌کاره به شمار می‌رود. در این فرآیند، ولتاژ قوس، شدت جریان جوشکاری و سرعت جوشکاری متغیرهای اصلی می‌باشند که می‌توانند به شدت خواص مکانیکی فلز جوش را تحت تأثیر قرار دهند. بر اساس منابع موجود، به رغم این که تاکنون کارهای تحقیقاتی بسیاری در مورد فرایند جوشکاری قوسی با گاز محافظ انجام شده است اما هنوز پژوهش‌های تجربی کمی در مورد انرژی ضربه فلز جوش به ویژه در فولادهای با کربن متوسط وجود دارد. انرژی ضربه فلز جوش از اهمیت بسیار بالا به ویژه در سازه‌هایی که در معرض بارهای ضربه قرار دارند، برخوردار است. بنابراین، مقاله پیش رو به هدف مطالعه تاثیر متغیرهای فرایند جوشکاری قوسی با گاز محافظ روی انرژی ضربه فلز جوش در فولاد کربنی CK45 تهیه شده است. نتایج حاصل از این مقاله نشان داد که مقدار حرارت ورودی در جوشکاری و نیز ابعاد گرده جوش در شرایط مختلف، عوامل اصلی تأثیرگذار بر انرژی ضربه فلز جوش می‌باشند.