Experimental Investigations of the Plasma Arc Cutting of AISI 1020 Carbon Steel Plate

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Paper History:

Received: 13th Nov. 2023

Revised: 24th Nov. 2023

Accepted: 27th Nov. 2023

Abstract

The current study presents the plasma cutting process of 2 mm thickness of AISI 1020 carbon steel. The experiment conducted by taking into the account the effect of two process parameters, including cutting current of 15 and 20 A with cutting speed in range of 500 - 4000 mm/min, on the kerf formation, microstructure and microhardness.

The results showed that at low cutting current of 15 A the melting occurred at the workpiece surface without cutting action. Increase the current to 20 A led to full penetration of the workpiece material at low and high cutting speed, with kerf width between 1.26 mm and 1.1 mm for cutting speed of 500 mm/ min and 4000 mm/ min, respectively. The plasma arc cutting speed has a high impact on the heat-affected zone HAZ and microstructure development with coarse grains at the HAZ at low cutting speed of 500 mm/min and constant current of 20A, increase the plasma cutting speed led to decreasing the grain size. The microstructure of the HAZ exhibited a presence of perlite and ferrite with some martensite structure. The highest microhardness of the HAZ of 220.8 HV was found in the sample processed at 20 A current and high cutting speed of 4000 mm/ min. However, the minimum microhardness of the HAZ of 156.7 HV was found in the sample processed at 20 A current and low cutting speed of 500 mm/ min.

Keywords: Plasma Arc Cutting, Microstructure, Microhardness.

دراسة عملية لعملية قطع بالبلازما للوح الفولاذ الكربوني AISI 1020

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الخلاصة:

تعرض الدراسة الحالية عملية القطع بالبلازما للوح من الفولاذ الكربوني AISI 1020 بسماكة ٢ ملم. تم إجراء التجربة مع الأخذ في الاعتبار تأثير متغيرين للعملية، بما في ذلك تيار القطع ١٥ و٢٠ أمبير مع سرعة قطع تتراوح بين ٥٠٠ - ٤٠٠٠ ملم/دقيقة، على تكوين الشق والبنية المجهرية والصلادة الدقيقة.

أظهرت النتائج أنه عند تيار القطع المنخفض البالغ ١٥ أمبير حدث انصهار المعدن على سطح قطعة العمل دون حدوث القطع. أدت زيادة التيار إلى ٢٠ أمبير إلى اختراق كامل لقطعة العمل عند سرع القطع المنخفضة والعالية، عرض الشق بين ١,٢٦ ملم و١,١ ملم لسرعة القطع ٥٠٠ ملم / دقيقة و٤٠٠٠ ملم / دقيقة، على التوالي .سرعة القطع بقوس البلازما لها تأثير كبير على منطقة التأثير الحراري HAZ وتطور البنية المجهرية وتكون الحبوب الخشنة في HAZ عند سرعة قطع منخفضة تبلغ ٥٠٠ م / دقيقة وتيار ثابت قدره ٢٠ أمبير، زيادة سرعة قطع البلازما أدى إلى تقليل حجم الحبيبات. أظهرت البنية المجهرية لـ HAZ وجود البيرلايت والفرايت مع بعض بنية المارتنسايت. تم العثور على أعلى صلادة مجهرية لـ HAZ تبلغ ٢٢٠,٨ HV في العينة التي تمت معالجتها عند تيار ٢٠ أمبير وسرعة قطع عالية تبلغ ٤٠٠٠ م / دقيقة. لكن الحد الأدنى من الصلادة المجهرية لـ HAZ تبلغ ١٥٦,٧ HV في العينة التي تمت معالجتها عند تيار ٢٠ أمبير وسرعة قطع قليلة تبلغ ٥٠٠ م / دقيقة.

1. Introduction

The plasma arc cutting PAC process is considered as one of the important non-traditional machining processes that utilized to machine different materials including titanium, aluminum, copper, steel and its alloys, along with difficult to cut materials, in additional, PAC is widely used to increase the productivity and overcome the cutting cost [1-3]. In this process a high velocity stream of ionized gas such as nitrogen, hydrogen, oxygen and compressed air with high temperature in the range of 10000 C° to 32000 C° used to cut the material through melting and blowing the molten metal to form the cutting. The plasma arc is generated between the negative polarity electrode inside the torch and positive polarity of the workpiece, the cutting gas is ionized due to the energy of this arc, Fig.1 presents a schematic drawing of the plasma cutting process [4-7].

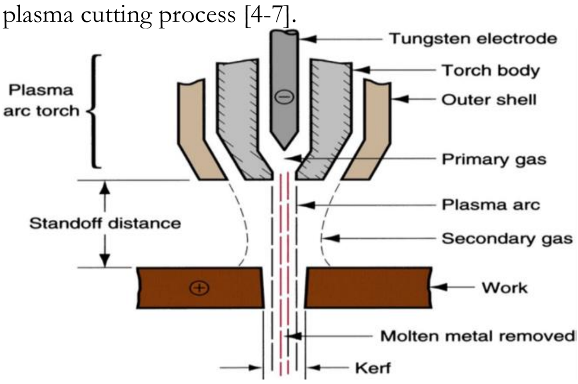

Figure (1): Schematic drawing of plasma arc cutting process PAC [8].

The efficiency of PAC is depending on several parameters including gas types cutting current, speed, standoff distance and gas pressure , many researchers have been studied the effects of process parameter in different aspects, for example, Naik and Maity [8] investigate the effects of flow rate and plasma gases types (air, oxygen, argon, and nitrogen) on the arc generated properties and the cutting performance of hardox-400, the results demonstrate that using nitrogen and air led to obtained a narrow kerf, however, wider kerf is obtained by using argon gas, the better cutting quality obtained using a high gas flow rate. Duplak *et. al.* [9] investigate the effects of plasma current, gas pressure and the traverse speed on the cutting roughness of S355 structural steel. Hema and Ganesan [10] report the optimum parameter for applying plasma arc machining PLM of 304 stainless steel is 2000 mm/min cutting speed 2 mm standoff and 136 V applied voltage. Lazarevic [11] investigated the effects of the cutting speed, current and the workpiece thickness of X10CrNiMn-16-10-2 stainless steel on the cutting roughness and the kerf. Aldazabal [12] studied the microstructures and the distribution of residual stress of the plasma arc cutting edges of 15 mm S460M steel. Ramakrishnan *et. al* [13] applied L9 orthogonal array to investigate the effects of plasma process parameters including cutting speed, standoff distance, current and gas pressure on the kerf width, roughness and the heat-affected zone, the authors conclude that the average contribution of cutting speed about 0.59%, standoff distance of 3.5%, with the current of 93.75% and gas pressure 2.13%.

The present work is aimed to identify the effects of plasma process variables on the kerf formation, microstructure and microhardness, and identify suitable combination of cutting parameters of AISI 1020 carbon steel.

2. Experimental work

In the present work, the workpiece material selected for the experimentation is 2 mm thickness of AISI 1020 carbon steel, the chemical composition of the workpiece is performed using a Spectro analytical instrument Table 1, a plate of 100 mm X 100mm X 2mm were prepared for the plasma cutting experiment.

Table (1): A chemical composition of AISI 1020

Elements %	
C	0.211
Si	0.0188
Mn	0.352
P	0.0115
S	0.0045
Cr	0.0087
Mo	0.0020
Ni	0.0192
Al	0.0322
Cu	0.0047
F	Bal.

The experimental work was conducted on a portable plasma cutting machine model Parkside PPS 40 B2, air compressor was attached to the plasma machine to provide the air pressure necessary for the cutting process. The cutting torch is connected to a ball screw linear motion to provide the cutting feed, the torch position is kept vertical regarding to the workpiece plate, Mach 3 Breakout Board controller with Mach 3 software is used to control the cutting speed motion, Fig.2 presents the experimental setup of the plasma arc cutting process.

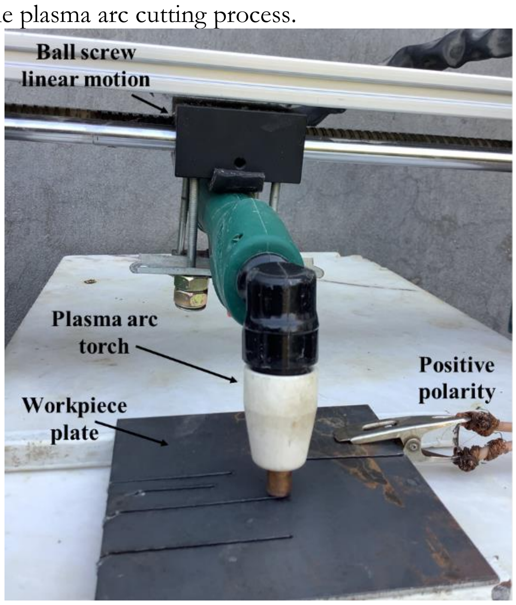

Figure (2): Experimental setup of plasms arc cutting.

The applied cutting current and speed was used as a variable parameter at 15, 20 A with 500, 1000, 2000 and 4000 mm/ min. The rest of processing condition was kept constant including gas pressure 2 bar, standoff distance 1 mm and nozzle diameter of 1mm, a compressed air was used as a plasma cutting gas.

A small section in the middle of one side of each cut was cut by using of samples cutting machine, the sectioned samples then mounted, grinded with sandpaper and polished. The samples washed with acetone and treated with etching solution of Nital (3 ml HNO_3 and 97 ml ethyl alcohols), an optical microscope model Olympus microscope equipped with a digital camera was employed for metallurgical analyses. The microhardness analyses were performed on the sectioned samples using Micro Vickers hardness at 500g and 15s dwell time.

3. Results and discussion

Fig.3 presents the plasma cut samples prepared at 15 A cutting current with 500, 1000, 2000 and 4000 mm/min cutting speed. At low cutting speed 500 and 1000 mm/min melting occur on the workpiece surface beginning of cutting line followed by the cutting action Fig.3a&b, in this case, the metal finds the time to gain heat at the beginning of the cutting line led to increase the temperature of the plate. At high plasma cutting speed and 15 A current the cutting did not reach the bottom of the workpiece, no cutting action has been occurred Fig.3c&d, similar results reported by Cinar *et.al* [14], this is probably attributed to the insufficient heat generated at low current with high cutting speed

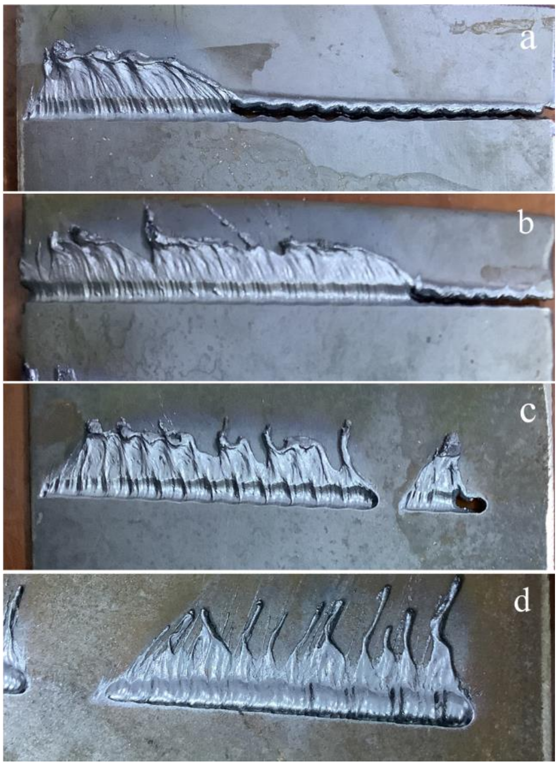

Figure (3): Top and bottom side of the plasma arc cut of 15 A cutting current and (a) 500, (b) 1000 (c) 2000, and (d) 4000 mm/min each.

Fig.4 shows top and bottom side of the plasma cut at 20 A cutting current and 500, 1000, 2000 and 4000 mm/ min cutting speed, it can be seen a non-uniform kerf width which is probably due to the non-uniform heat distributions along the kerf, a similar result was reported [8, 15].

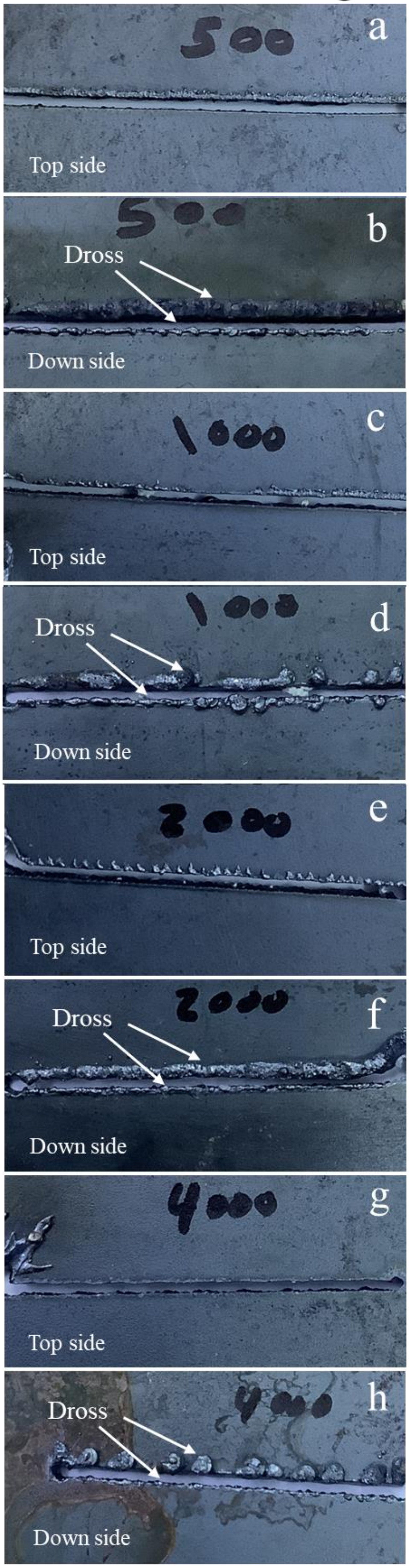

Figure (4): Top and bottom view of the arc cut samples at 20 A current with 500, 1000, 2000 and 4000 mm/min cutting speed.

The dross is formed from the molten material that flow during plasma cutting from the kerf, it is difficult to measure the dross because the appearances, size, shape, and removability are different at each cutting parameters, again, similar results have been reported by Ramakrishnan *et. al* [16]. The metal melts from the front surface of the cut and forces by high compressed air and plasma jet flow over the cutting line and eject from the bottom of the plate, some of the molten metal adhere at the edge of the kerf and solidified.

Figure 5 presents the kerf width measured in mm as a function of increasing cutting speed of 500 to 4000 mm / min at 20 A cutting current, the kerf width is about 1.26 mm for the cutting speed of 500 mm / min and 20 A current, increase the cutting speed led to slightly decrease kerf width, with 1.1 mm kerf width at 4000 mm/ min and 20 A current.

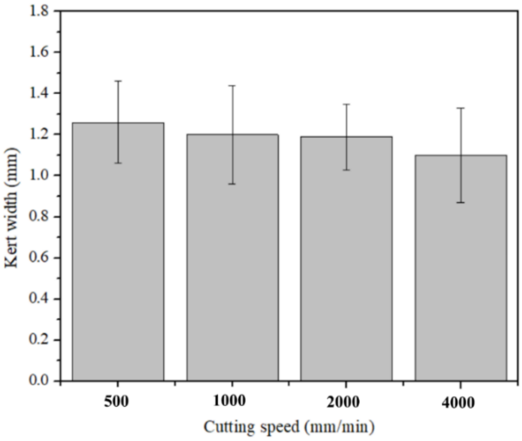

Figure (5): Kerf width at 20 A cutting current and 500, 1000, 2000, 4000 mm/min cutting speed.

Figure 6 presents the microstructure including heat affected zone HAZ and re-solidified zone of samples processed at cutting current of 20A and speed 500, 1000, 2000 and 4000 mm / min. The HAZ is distinguished by the coarse grain near the plasma cutting surface, it can see the HAZ decrease with increase the cutting speed. The using of high cutting speed at constant current led to reduce the plasma time on the workpiece surface results in less HAZ.
The microstructures of the as received AISI 1020 carbon steel demonstrates the presence of ferrite / pearlite structure [17]. The HAZ microstructure of the sample processed with 20A current and 500 mm/min cutting speed presents coarse grain size Fig.6a, this is probably due to the amount of energy at low cutting speed. Increase the cutting speed to 1000, 2000, 4000 mm/min led to decrease the grain size Fig.6a, b & c. In general, the microstructure of the HAZ exhibits a high amount of perlite to ferrite structure, with presence of some martensite which is typical of plasma cutting steel [18, 19]. The martensite transformation occurred due to high cooling rate during plasma cutting process.

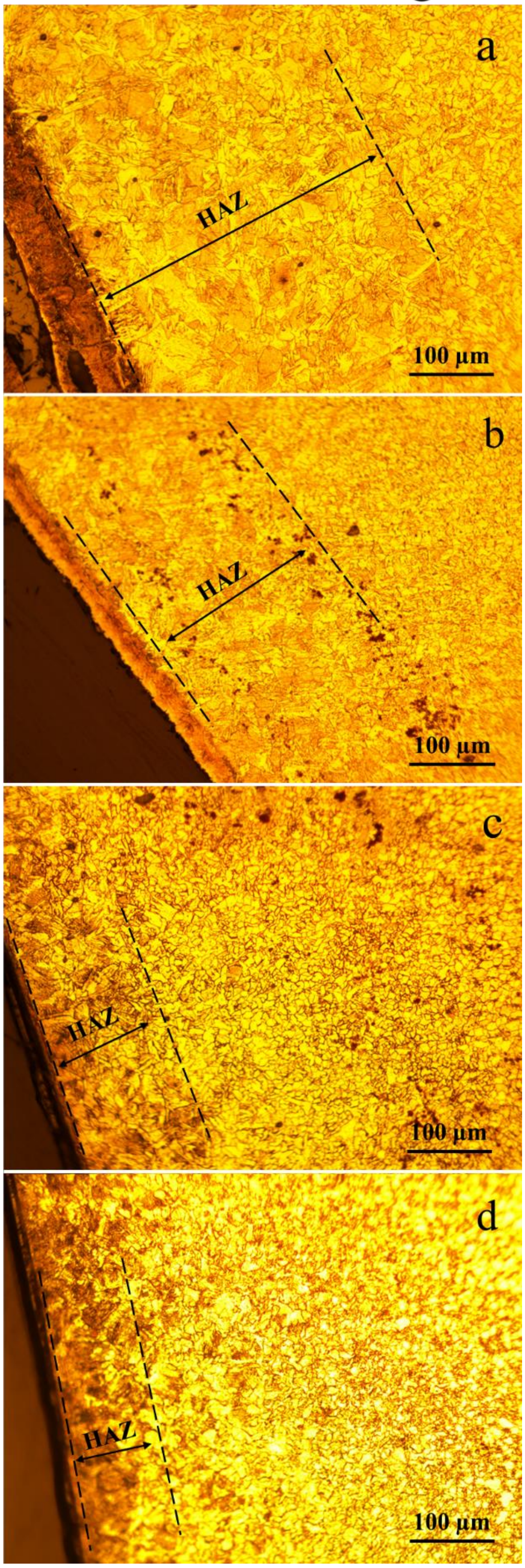

Figure (6): The microstructure of the plasms cutting samples processed at 20 A current and cutting speed of (a) 500, (b) 1000, (c) 2000, and (d) 4000 mm/min each.

Fig.7 presents a representative low and high magnified image of the microstructure of the sample processed at 20 A current and 500 mm/min cutting speed, again, the HAZ has a perlite and ferrite with martensite structure. Evidence of the presence of small microcracks in the re-solidified layer Fig.7b.

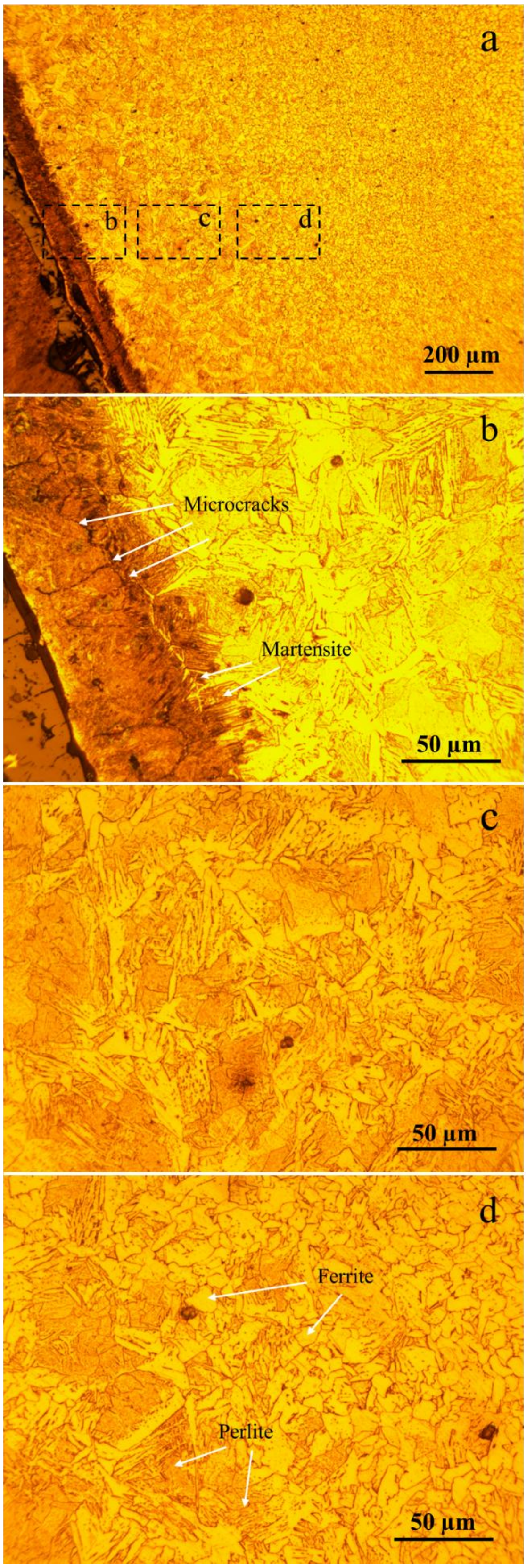

Figure (7): Low and high magnification of the of the microstructure of the sample processed at 20 A current and 500 mm/min cutting speed.

Fig.8 presents the microhardness of the as received AISI 1020 carbon steel and HAZ of the plasma cutting samples, the microhardness of the as received plate is about 171.8 HV, a similar result reported by Cardona et.al [20]. The microhardness of the sample processed at low cutting speed 500 mm/min was 156.8 HV which it slightly less than that of the as received material, this is probably due to the coarse grain of the HAZ Fig.6a, increase the cutting speed 1000, 2000 and 4000 mm/m results in increase the microhardness to around 186.6, 203.3 and 220.8 HV, respectively, the small grain size and presence of perlite with some martensite led to increase the hardness with increase the plasma cutting speed.

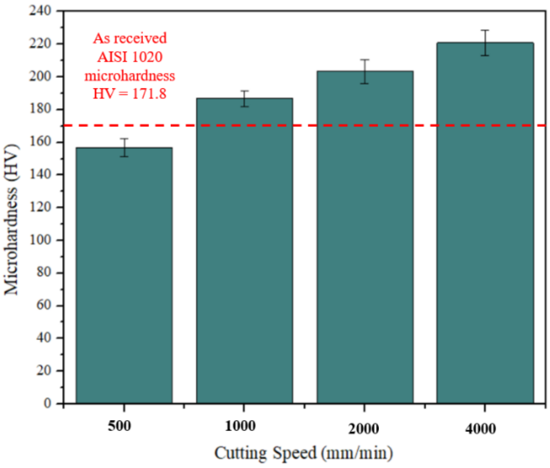

Figure (8): The microhardness of the as received AISI 1020 carbon steel and plasms cutting samples processed at 20 A current and cutting speed of (a) 500 mm / min (b) 1000 mm / min, (c) 2000 mm / min and (d) 4000 mm / min.

4. Conclusion

The selection of suitable cutting parameters for the plasma cutting is considered as a critical factor in determining the cutting quality. This research is attempting to investigate the cutting quality of 2 mm thickness of AISI 1020 carbon steel, the main results are described as follows:

1- The melting occurred at the workpiece surface at the starting cutting line followed by cutting action at the middle and the end of the cutting line at low current of 15 A and low cutting speed of 500 and 1000 mm/min. However, the melting occurred at the workpiece surface without cutting action at low current 15 A and high cutting speed of 2000 mm / min and 400 mm / min.

2- The HAZ increase with decrease the plasma cutting speed at constant cutting current.

3- The cutting speed has a high effect on the microstructure development with coarse grain at the HAZ at low cutting speed. Increase the speed of cutting results in decreasing the grain size.

4- The microstructure of the HAZ exhibited a presence of a high amount of perlite to ferrite with some martensite structure.

5- The lowest microhardness of HAZ of 156.8 HV was found in the sample processed at low cutting speed 500 mm/min and current of 20 A, increase the cutting speed to 4000 mm/ min led to increase the microhardness 220.8 HV.

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