Study of the Effect EDM Process Parameter of Current Discharge on the Hardness of the Material AISI 316 Food Grade with Copper and Graphite Electrode

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Abstract: Electrical Discharge Machining (EDM) is a non-conventional machining process that uses thermal energy in the form of high-temperature electrical discharge of 10,000˚C - 12,000˚C occurring between the chisel and workpiece as the cutting media. The EDM process produces a high degree of precision for complex product shapes and good surface quality. This study aims to find the optimum parameter combination of the AISI 316 EDM material process. The independent variables of the research are discharge current (6A, 12A, 21A) and electrodes (Copper and Graphite). Fixed variables used are Pulse on time 120 µs, Pulse off time 3 µs, voltage 45 V, kerosene CPC dielectric liquid, AISI 316 material, type of EDM sinker machine SKM EDM State Polytechnic of Jakarta. Control variables are macro hardness, microhardness. The highest Vickers microhardness test is 229,062 HV when the discharge current is 12 A, and the copper electrode is at the surface (Recasting), and the lowest is 163,648 HV when the discharge current is 12A in the Recasting layer. Rockwell macro hardness is the highest hardness when the discharge current is 21A which is 11 HRC or 187.343 HB, and the lowest is 6A 6 HRC or 165.458 HB.

Keywords: EDM, AISI 316 Food-Grade, Sinker EDM, Hardness.

1. INTRODUCTION

Compaction using dies and punches is widely used for manufacturing tablets of the medicine. Manufacture of dies/punches requires high surface smoothness (Maghsoudi et al., 2017). The quality of the tablets or food products produced in compaction depends on the quality of the surface of the mold dies/punches made. The rough surface of the dies/punches can trap particles of medicine that can be a source of health problems (expired medications and corrosion). Dies/punches for medicine and food production have to qualify safety standards for health because the equipment can cause a reaction addiction or absorb the medicinal materials and not a harmful effect on the product.

The Indonesian Agency for Food and Drug Administration (BPOM RI), Chapter 4 article 4.2 and article 4.7, regulates the surface of the tools that contact with the raw material, intermediate products, or the finished product should not cause a reaction, addition, or absorption. That reaction can affect the identity, quality, or purity beyond the limit specified. Furthermore, production equipment used should not harm the product, and parts of the production equipment that come into contact with the product must not be reactive, additives, or absorptive, affecting the quality and harmful effects on the development.

EDM (electrical discharge machining) machine is non-conventional the using energy sparks (spark) with a large electrical current between the mold (the cathode) and the workpiece (anode) to the process of metal cutting (Ettefagh, 2021). EDM is a non-conventional machining process that uses the energy of stepping sparks with the electric current density, which is excellent

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for metal cutting. Results the operation of the EDM sinker is strongly influenced by several process parameters such as the current discharge, pulse on time, and servo sensitivity. Spark produces temperatures reached 10.000C will leave a crater cutting and increase the hardness of the surface material. Hot EDM is a high-yielding three-layer area with different characteristics, namely the top layer (recast layer), a second layer called the heat-affected zone (HAZ), and bulk material. Phenomena and micro-structure produced in the recast layer there is a structure casting or welding, whereas in the second layer delivers microstructure of heat treatment with marked regions its heat.

Based on the literature and previous research, this research will focus on the change parameter process changes on the process of EDM sinker because the process is susceptible to changes in parameters processes such as discharge current and type of material processed. Spark with a temperature of 10,000 °C will leave a crater cutting and increase the surface hardness. The value of these parameters also have an impact on result surface hardness so that the obtained value of the parameter that the optimum value of the adequate.

2. LITERATURE REVIEW

EDM is a machining process non-conventional. Different machining techniques of conventional wear a knife cutting machine, EDM forming the workpiece utilizing releasing the electric arc (electrical discharge/spark) through two electrodes(Ashok Kumar et al., 2017). The electric arc of this raises a very high heat (about 10,000°C) to erode the workpiece. Electric control system resulted in the release of electric arc controlled so continuously erode and shape of the workpiece. The dielectric liquid is used as a medium that serves to flush the remnants of a material particle erosion, cooling the electrode and workpiece and electrical conductors. There is 2 type of EDM machine that is sinker EDM and wire EDM. This research using sinker EDM, and then the schematic wire EDM is shown in Figure 1. Process cutting material (material removal) in EDM mainly occurs due to shock waves forming as the plasma channel ion-exchange power, as shown in Figure 2.

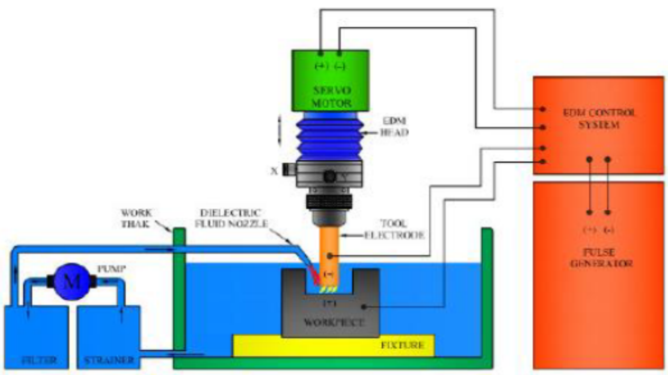

Figure1 - Schematic Sinker EDM (Janmanee and Muttamara, 2011)

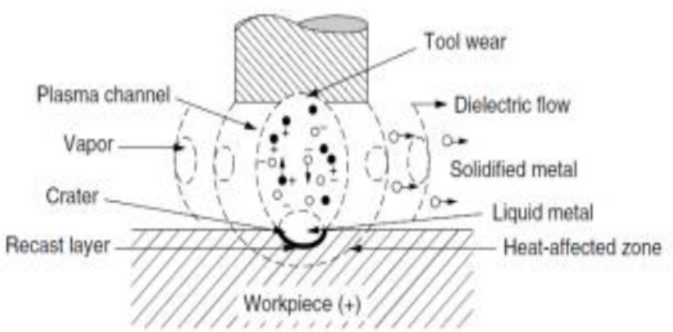

Figure 2 - Spark forming process (Skoczypiec et al., 2015)

EDM machine suitable for cutting material, if the workpiece is shaped as follows: The walls are skinny, holes with a tiny diameter, the ratio of the height and diameter of a very large, the workpiece are very small, complex in the chuck. The process of EDM sinker is susceptible to changes in process parameters such as discharge current, pulse on time, servo sensitivity, and type of material processed. In Figure 3, EDM produces the typical structure consists of 3 layers, namely recast layer, HAZ layer, and the bulk material (Kumar et al., 2021).

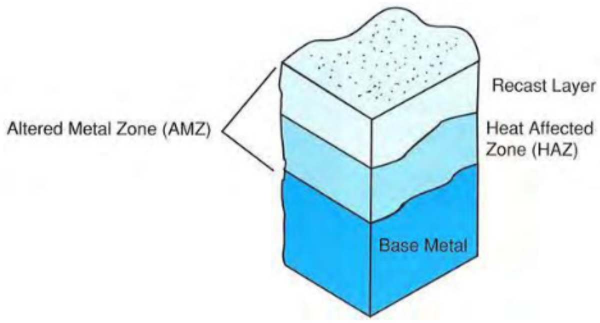

Figure 3 – Recast Layer, HAZ zone and bulk material (Minna, 2015)

For hardness testing on the surface of a material, use macro hardness, while below the characters, use microhardness. Macro hardness fulfills the standard ASTM E10 Standard Test Method for Brinell Hardness of Metallic Materials. The indentation on the stainless steel AISI 316 using a ball indenter with a unit that produced HBN. Microhardness has a solid relationship with the results of the process of EDM. Standard ASTM E384-11, applied for micro Vickers Hardness of Materials. Tracking was done with the load magnitude that can be arranged according to the hardness of the material tested.

3. METHODOLOGY

The material used was stainless steel AISI 316 food grade with size 25 x 19 mm x 10 mm for thirty samples (fifteen for electrode cooper and fifteen for electrode cooper). Chemical specification for material AISI 316 food grade that is 0,08 %C, 2 %Mn, 16 %Cr, 14 %Ti, 2 %Mo. This research used two electrodes is cooper and carbon. The properties of copper and carbon electrode are shown in Table 1.

Table 1 - properties of cooper and carbon electrode

Properties	**Copper (99%)**	**Carbon (99%)**
Melting point	1085°C	1060 °C
Density	8.96 g/cm3	2.267 g/cm3
Thermal conductivity	401 W/mK	119-165 W/mK
Electrical Resistivity	1.673 μΩ-cm @ 20°C	0.0035 μΩ -cm @ 20°C
Specific Heat	0.39 kJ/kg K	0.71 J/g K

4. DATA ANALYSIS AND DISCUSSION

4.1 Micro hardness Results of the EDM Process

Testing the hardness of the micro was performed on the six pieces of the sample with the free variable discharge current 6A, 12A, and 21A. Testing conducted from the surface area of the Recasting, the Area of the Heat Affected Zone (HAZ), and the area of the Base Metal. The thickness of the sample will be tested by 10 mm, and the tracking was done ten times on a different test. The results of the microhardness of each piece is shown in Table 2.

Table 2 - The results of the micro hardness of cooper electrode

Sample	Current Discharge	Electrode	Position Test	Point	d [μm]	HV [Gf/μm²]	HV Rata – rata
1	6 A	Cooper	Recasting	1	29.61	211.5079051	193.9220075
				2	30.98	193.2148899	
				3	29.84	208.2599602	
				4	32.43	176.3232253	
				5	32.07	180.304057	
			HAZ	6	31.88	182.4596314	172.8120132
				7	32.24	178.4076006	
				8	33.46	165.6347839	
				9	31.56	186.1784582	
				10	35	151.3795918	
Sample	**Current Discharge**	**Electrode**	**Position Test**	**Point**	**d [μm]**	**HV [Gf/μm²]**	**HV Rata – rata**
2	12 A	Cooper	Recasting	1	26.69	260.319242	229.062744
				2	27.24	249.9132096	
				3	28.35	230.7264012	
				4	30.59	198.1729912	
				5	29.99	206.1818761	
			HAZ	6	27.54	244.4981328	218.6782964
				7	29.69	210.3696205	
				8	27.86	238.9137772	
				9	29.46	213.6672368	
				10	31.58	185.9427147	
Sample	**Current Discharge**	**Electrode**	**Position Test**	**Titik Uji**	**d [μm]**	**HV [Gf/μm²]**	**HV Rata – rata**
3	21 A	Cooper	Recasting	1	33.15	168.7471136	171.0148844
				2	32.46	175.9974549	
				3	32.74	172.9999862	
				4	31.26	189.7690884	
				5	35.45	147.5607791	
			HAZ	6	34.32	157.4377449	167.6465002
				7	32.46	175.9974549	
				8	32.83	172.0527637	
				9	34.54	155.4385557	
				10	32.34	177.3059817	

Based on the above Table showed the results of microhardness in the surface layer (Recasting) to the core layer (HAZ) is described in Figure 4.

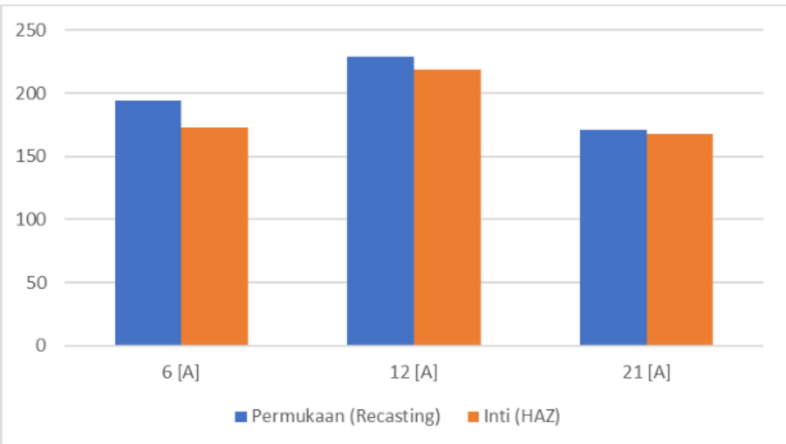

Figure 4 - The results of micro hardness with copper electrodes EDM process

Figure 4 indicates the results of the microhardness testing on three samples. Free Variable discharge current 6A; 12A; 21A. The parameters of the fixed electrode copper. At the time of the discharge current 6 [A] the obtained value of microhardness in the Lining of Recasting 211,507 HV, 193,214 HV, 208,259 HV, 176,323 HV, 180,304 HV and a layer of HAZ 182,459 HV, 178,407 HV, 165,634 HV, 186,178 HV, 151,379 HV.The discharge current 12A Layer Recasting hardness value 260,319 HV, 249,913 HV, 230,726 HV, 198,172 HV, 260,181 HV, and a Layer of Haz hardness values 244,498 HV, 210,368 HV, 238,913 HV, 213,6942 HV, 185,913, and at the time of the discharge, current 21A results of the hardness of the Coating Recasting that 168,747 HV, 175,997 HV, 172,999 HV, 189,769 HV, 147,560 HV, and a Layer of Recasting 157,437 HV, 175,997 HV, 172,052 HV, 155.438 HV, 177,305 HV. The hardness of the sample's surface (Layer Recasting) is hard compared to the core Layer (HAZ). EDM process causes only part of the surface Layer (Recasting) the hardest and the core Layer (HAZ)) more lenient. With the increase in the discharge current, the temperature during the EDM process increased that impacts on increasing the amount of carbon content on the surface of the material exposed to the heat of the process of Electrical Discharge Machining (EDM). Increase the amount of carbon deposited on the material caused by carbon deposition of the electrodes and the dielectric liquid that occurs in the process of flushing on the material's surface. The number of carbon deposition on the surface of the material triggers an increase in hardness values.

Table 3 - The results of the micro hardness of graphite electrode

Sample	**Current Discharge**	**Electrode**	**Position Test**	**point**	**d [µm]**	**HV [gF/µm²]**	**HV Rata - rata**
4	6 A	Graphite	Recasting	1	31.31	189.1634749	216.6891093
				2	31.71	184.4212386	
				3	29.56	212.2240309	
				4	27.25	249.7298207	
				5	27.35	247.9069814	
			HAZ	6	26.93	255.6999904	213.0319797
				7	28.05	235.6881174	
				8	30.46	199.8681629	
				9	31.41	187.960913	
				10	31.58	185.9427147	
Sample	**Current Discharge**	**Electrode**	**Position Test**	**point**	**d [µm]**	**HV [gF/µm²]**	**HV Rata - rata**
5	12 A	Graphite	Recasting	1	32.15	179.4078593	164.8125569
				2	33.42	166.0315138	
				3	33.47	165.5358236	
				4	34.02	160.2266675	
				5	34.83	152.8609202	
			HAZ	6	33.78	162.5115109	163.6484977
				7	32.59	174.596164	
				8	34.89	152.3356254	
				9	32.74	172.9999862	
				10	34.5	155.7992018	
Sample	**Current Discharge**	**Electrode**	**Position Test**	**point**	**d [µm]**	**HV [gF/µm²]**	**HV Rata - rata**
6	21 A	Graphite	Recasting	1	32.61	174.3820669	169.5448876
				2	33.18	168.4421031	
				3	33.47	165.5358236	
				4	33.24	167.8345577	
				5	32.88	171.5298868	
			HAZ	6	33.39	166.3299973	168.860956
				7	33.55	164.7473242	
				8	33.68	163.4779763	
				9	32.71	173.3174658	
				10	32.42	176.4320164	

Based on Table 3 above, obtained results of the microhardness of the surface Layer(Recasting) to the core Layer (HAZ) are described in Figure 4 below.

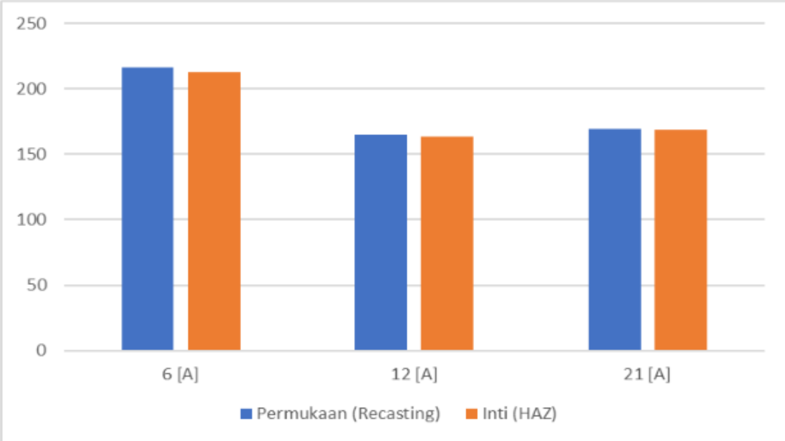

Figure 5 - The results of micro hardness with graphite electrodes EDM process

Figure 5 indicates the results of testing the hardness of micro on three samples. Free Variable discharge current 6 A; 12A; 21A. The parameters of the fixed electrode graphite. At the time of the release current 6 [A], the obtained value of microhardness in the Lining of Recasting 189.163 HV, 184.421 HV, 212.224 HV, 249.729 HV, 247.906 HV, and a layer of HAZ 255.699 HV, 235.688 HV, 199.686 HV, 186.960 HV, 185.942 HV. At the time of the discharge current 12A, microhardness was obtained in the Lining of Recasting 179.407 HV, 166.031 HV, 165.535 HV, 160.226 HV, 152.860 HV, and a Layer of HAZ 162.511 HV, 174.596 HV, 152.335 HV, 172.999 HV, 155.799 HV. At the discharge, current 21A obtained the value of microhardness in the Lining of Recasting 174.382 HV, 168.442 HV, 165.535 HV, 167.834 HV, 171.529 and a Layer of HAZ 166.329 HV, 164.746 HV, 163.477 HV, 173.317 HV, 176.432 HV. The results of microhardness show that. The sample (Layer Recasting) surface is complex compared to the core Layer (HAZ).EDM process causes only part of the surface Layer (Recasting) the hardest and the core Layer (HAZ)) more lenient. With the increase in the discharge current, the temperature during the EDM process increased, improving the amount of carbon content on the surface of the material exposed to the heat of Electrical Discharge Machining (EDM). Increase the amount of carbon deposited on the material caused by carbon deposition of the electrodes and the liquid dielectric that occur in flushing on the material's surface. The number of carbon deposition on the surface of the material triggers an increase in hardness value.

4.2 The hardness of the Macro Results of the EDM Process

Hardness testing the macro after Electrical Discharge Machining was carried out on six samples with free variable discharge current is 6 A, 12 A, and 21 A with copper electrodes and graphite. The Hardness of a Macro before Electrical Discharge Machining managed to track three times on the six samples. Tracking was done three times at different points. The results of the hardness testing macro shown in Table 4 below:

Table 4 - The results of the macro hardness Before EDM Process

Specimen	Current Discharge	Electrode	Hardness test [HB]			Average	HRC
			I	II	III	HB	
1	6 [A]	Cu	208.71	204.58	210.83	208.04	13.4
2	12 [A]	Cu	206.63	204.58	206.63	205.946	13.4
3	21 [A]	Cu	212.97	206.63	208.71	209.436	15.7
4	6 [A]	Graphite	210.83	206.63	204.58	207.346	13.4
5	12 [A]	Graphite	204.58	206.63	208.71	206.64	13.4
6	21 [A]	Graphite	204.58	206.63	210.83	207.346	13.4

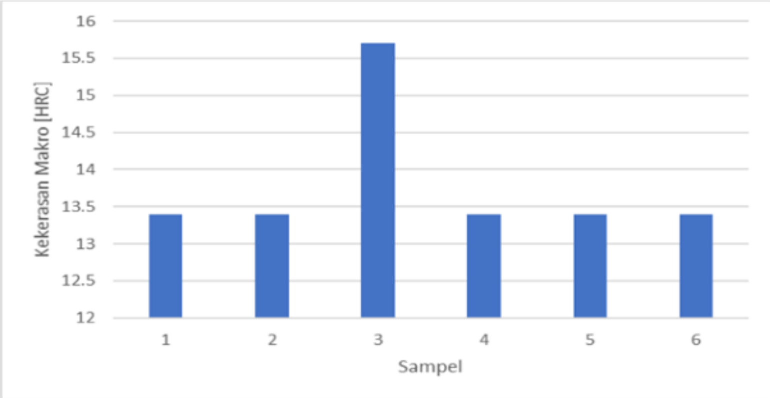

Figure 6 - The results of macro hardness before EDM process

Figure 6 above shows the results of hardness macro using the indentation of the ball on testing Brinell before the process of Electrical Discharge Machining. Violence macro on the first sample of 13.4 HRC or 208.04 HB, a second sample 13.4 HRC or 205.946 HB, sample third 15.7 HRC or 209.436 HB, sample fourth 13.4 HRC or 207.346 HB, sample fifth 13.4 HRC or 206.64 HB, sample sixth 13.4 HRC or 207.346 HB. The first sample would be machined process with the discharge current 6A and copper electrodes. A second sample discharges current 12A copper electrodes. The third sample is the discharge current 21A copper electrodes, four discharge present 6A electrode graphite, sample five discharge current 12A of the electrode graphite, a model of six discharge current 21A of the electrode graphite. A discharge current of 6 A and 12A implemented for samples with the same hardness equal to 13.4 HRC or 210.83 HB and 206.63 HB. Fatherly, while the discharge current of 21 A has A hardness value of 15.7 HRC or 209.436 HB on the electrode copper, graphite has a hardness of 13.4 HRC or 210.83 HB.

Hardness testing the Macro after the process of Electrical Discharge Machining done tracking three times on the six samples with free variable discharge current, i.e., 6 [A], 12 [A], and 21 [A] with copper electrodes and graphite. Tracking was done three times at different points. The results of the hardness testing macro shown in Table 5 below:

Table 5 - The results of the macro hardness After EDM Process

Spesimen	Arus Discharge	Elektroda	Pengujian [HB]			Kekerasan Rata-Rata	Kekerasan HRC
			I	II	III		
1	6 [A]	Tembaga	165.198	165.98	165.98	165.458	6
2	12 [A]	Tembaga	166.73	166.73	166.73	166.73	6
3	21 [A]	Tembaga	168.281	168.281	168.281	168.281	6
4	6 [A]	Graphite	179.731	179.731	179.731	179.731	8
5	12 [A]	Graphite	181.456	181.456	181.456	181.456	8
6	21 [A]	Graphite	187.347	187.431	187.341	187.343	11

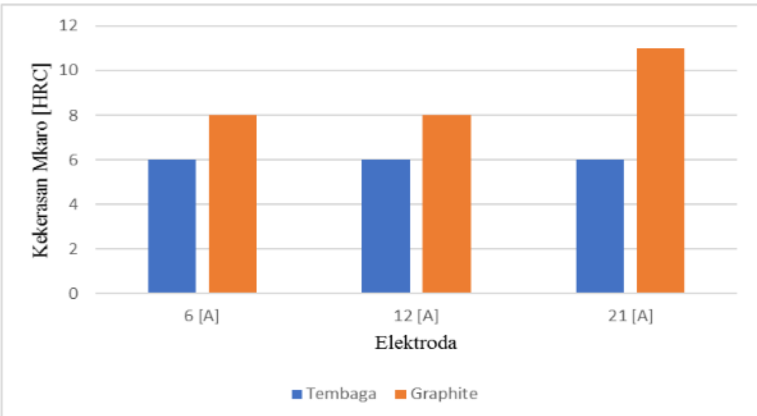

Figure 7 - The results of macro hardness after EDM process

Figure 7 above shows the results of hardness macro using the indentation of the ball on testing Brinell after the process of electrical discharge Machining. The macro hardness of specimen with the discharge current 6A and 12A with copper electrodes has a hardness value of 6 HRC or 165.458 HB and 166.72 HB, and on the discharge current of 6A and 12A of the electrode, graphite has a hardness of 8 HRC or 179.731 HB and 181.456 HB. While on the discharge current 21A on copper electrodes hardness value of 6 HRC or 168.281 HB and discharge current 21 A of the electrode graphite hardness value of 11 HRC or 187.341 HB. The discharge current of 6 A, 12 A, 21 A at copper electrodes influences the macro seen from the chart increased in the picture above. Likewise, on the discharge current 6 A, 12 A, and 21 A of the electrode graphite hardness of the macro rose. His slight enormous recent release and the electrode used to affect the surface hardness of the process of Electrical Discharge Machining (EDM). The hardness of a macro before and after the process of EDM decreased strength. It can be seen from the reduced carbon content. High carbon content can improve the hardness or stability of the material.

5. CONCLUSION

Testing the hardness of micro Vickers on the surface Layer (recasting) has a value higher hardness than the core Layer (HAZ). This increase is because when temperature increases, then the carbon content increased. The high carbon content makes the material becomes hard. Violence at the time of the discharge current 6A and copper electrodes on a layer of Recasting and a Layer of HAZ, namely 192.922 HV and 172.812 HV. The discharge current 12A of the electrode copper hardness value of the Coating Recasting and a Layer of HAZ, namely 229.062 HV and 218.678 HV. At the discharge current, 21A of the electrode copper hardness value of the Coating Recasting and a Layer of HAZ, namely 171.014 HV and 167.646 HV. At the discharge current 6[A], the electrode graphite hardness values in the Coating Recasting and a Layer of HAZ, namely 216.689 HV and 213.031 HV. At the time of the discharge current 12[A], the electrode graphite hardness value of the Coating Recasting and a Layer of HAZ, namely 164.812 HV and 163.648 HV. At the discharge current, 21A of the electrode graphite hardness value of the Coating Recasting and a Layer of HAZ, 169.544 HV, and 168.860 HV. Macro Brinell Hardness before and after the EDM process decreased.

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