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Analysis of Variations in the Number of Layers of Hardfacing Overlay Abrex 500 Material on Hardness, Impact Strength and Microstructure with the SMAW Process

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Abstract

Hardfacing is a welding technique that functions to increase the surface hardness value of a material. Generally, hardfacing is done on low-carbon steel materials because low-carbon steel cannot be increased in hardness by heat treatment. For this reason, research will be carried out on the multilayer hardfacing process with the aim of obtaining optimal layer hardness. The methodology in this research is that multilayer hardfacing welding will be carried out consisting of 3 layers, 4 layers, and 5 layers, and each specimen has 2 buffer layer layers with E 309 electrodes for the hardfacing layer using HV 600 electrodes. This research reveals the influence of the number of layers of hardfacing on the hardness and toughness values. ABREX 500 material with a size of 150x150x10 mm was welded using the SMAW process using a current of 130 A. In this research, hardness and toughness tests were carried out. On test results. The base metal microstructure is dominated by a tempered martensite structure with a small amount of bainite and pearlite. In the structural area of the support layer, austenite and vermicular ferrite dominate. In the hardfacing layer area, austenite and vermicular ferrite, which are in dendritic form, dominate. The increase in hardness will occur significantly after hardfacing is carried out on the base metal. In a specimen, the more layers of hardfacing are added, the harder the material will be. The hardness of the specimen in 5 layers gets the most optimal value (higher) when compared with the hardness in 3 layers and 4 layers. In the 5-layer specimen, the resulting hardness value was 482.13 kgf/mm^2, for the 4-layer specimen, the average value was 464.83 kgf/mm^2, and in the 3-layer specimen, the hardness value was 444.13 kgf/mm^2. For toughness testing, the highest toughness value was obtained, namely 1.32 (J/mm^2) for the 3 layers specimen, compared to 4 layers with a toughness value of 1.25 (J/mm^2) and 5 layer with a toughness value of 1.19 (J/mm^2). The toughness value decreases as the hardness value increases.

1. Introduction

The need for metal with a high wear rate continues to increase along with the development of various industries that require equipment with high hardness. These industries are the cement, mining, and heavy equipment industries. The metal surface is a very important part of the metal material because this part is in direct contact with the external environment. The bucket is one of the main components of an excavator that has direct contact with the external environment. Increasing the surface hardness of the bucket is very important because the bucket rubs directly against the material being worked on. The resistance of a material to compression can be measured by its level of hardness [1]. The increase in hardness will be directly proportional to the increase in wear resistance [2]. ABREX 500 is one of the metals used for excavator buckets, where this material has a good surface with a very high hardness, namely < 500 HBW [3].

However, when equipment made from ABREX 500 is applied in the field, problems often arise, which result in the material's lifespan being reduced and maintenance costs increasing. Apart from that, the problems that arise are the emergence of cracks and a decrease in hardness values. For this reason, research is needed to find ways to overcome these problems. The occurrence of material wear on excavator buckets The hardfacing method is one effort that can be made to increase surface hardness on low-carbon steel [4].

When welding the number of layers, the number of layers will be an influencing factor in the hardness value. The hardfacing process often uses a buffer layer. The use of a buffer layer is generally used for certain purposes, such as reducing stress and avoiding cracks [5]. Increasing the number of hardfacing alloys significantly reduces the dilution, increases the hardness, and improves the microstructure, thus, enhancing the overall mechanical characteristics of the deposits. Studies on iron-based hardfacing deposits with single- and double-layers show higher hardness and greater wear resistance in the double-layered samples.Earlier works have suggested that using multiple layers of deposit lowers the dilution and improves the distribution and size of hard phases in the microstructures, which increases the overall hardness of deposits[6].

This research aims to determine the effect of the number of layers consisting of 2 layers, 4 layers, and 5 layers on hardfacing overlays using E 309 electrodes and HV 600 electrodes on ABEX 500 material on the hardness, toughness, and microstructure values in base metal and weld metal (buffer layer).

2. Research Method

The welding process used in this research is the SMAW welding process (Shield Metal Arc Welding), also known as Manual Metal Arc Welding (MMAW) or wrapped electrode welding, which is a process of connecting two or more pieces of metal into a smooth connection. fixed, using an electric heat source and filler material in the form of wrapped electrodes. In the wrapped electrode welding process, an electric arc that occurs between the tip of the electrode and the base metal (workpiece) will produce heat. This heat is what melts the tip of the electrode (welding wire) and the workpiece locally. The electric arc is generated by a welding machine. The electrode used is a wire wrapped in a protective shield in the form of flux. With this melting, the weld seam will be filled with liquid metal originating from the electrode and base metal; a molten crater is formed, then it freezes, resulting in weld metal and slag. [7].

The material used in this research is ABREX 500, which is abrasion-resistant steel whose hardness is 500 HVN. This plate is used because of its wear-resistance properties. In addition, this plate displays an extraordinary combination of high resistance to corrosion, good weldability, sturdy construction, high hardness, good toughness, etc. Apart from that, its toughness and strength make it resistant to high wear. Even though this plate has a high hardness, it can be welded, drilled, milled, and cut using standard workshop techniques. ABREX 500 Steel is ideal for industrial applications such as hoppers, truck liners, buckets, etc. [8]. This research requires material for welding coupon tests. The dimensions of the material used are 150 mm wide by 150 mm long, with a thickness of 10 mm. It can be seen in Fig. 1.

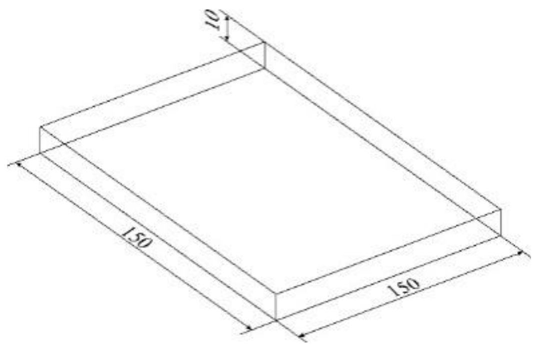


Fig. 1. Material dimensions

In this research, welding was carried out in 3, 4, and 5 layers, with 2 layers as buffer layers and an additional 1, 2, and 3 layers as hardfacing. Welding is carried out in the down-hand position using the SMAW process. To deposit the buffer layer, the E-309 electrode is used, while to deposit the hardfacing layer, the HV 600 electrode is used, and for the welding process, 1 current is used, namely 130 A. Hardfacing overlay welding is carried out 75 mm wide and 150 mm long. This is in accordance with ASME IX provisions that state the minimum width of overlay welding is 38 mm and the minimum length is 150 mm. Later, when welding specimens of 3, 4, and 5 layers, the layer arrangement for each variable will be explained in Fig.s 2 to 4 below. Where each of these is welded with a current of 130 A.

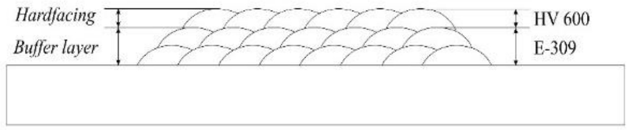


Fig.2. layer arrangement

Fig.3. layer arrangement

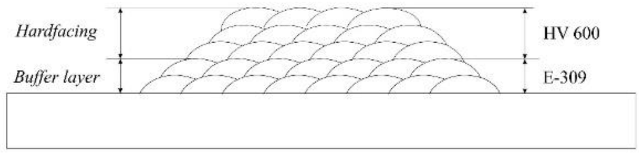
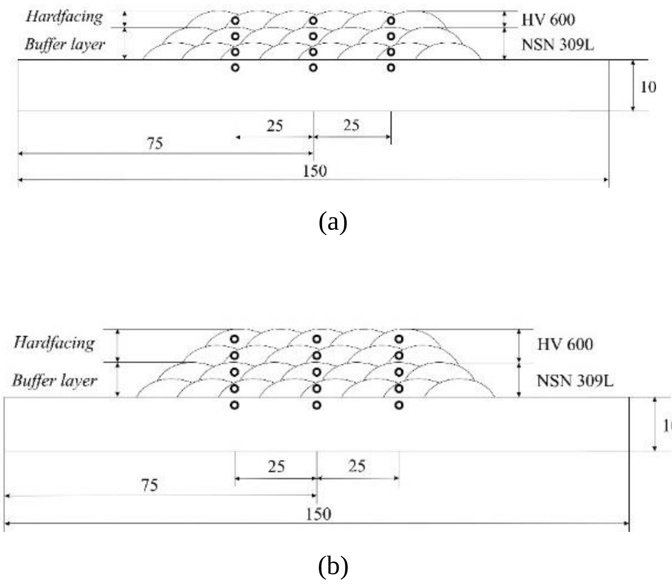
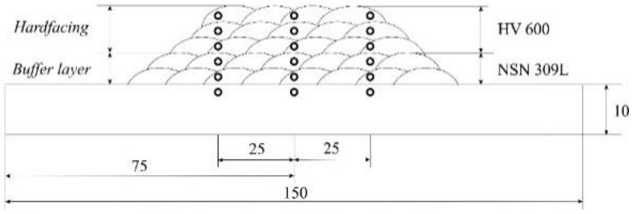


Fig.4. layer arrangement

After the welding process is carried out, the hardness testing process is carried out on the three specimens. A hardness test is a form of destructive testing that aims to determine the material's ability to accept loads without experiencing plastic deformation, namely resistance to indentation or penetration, resistance to scratching, and resistance to wear. This test uses the diamond pyramid method with a load of 10 kg and a loading time of 10 seconds. Vickers hardness testing using an indenter Taking the location of the hardness test in Fig. 5 below:





(c)
Fig. 5. Impact testing dimensions

After hardness testing, impact testing is carried out, which is an attempt to simulate material conditions that are often found in transportation or construction equipment where the load does not always occur slowly but comes suddenly. The principle of impact testing is the absorption of potential energy from a pendulum load that swings from a certain height and hits the test object so that the test object experiences deformation. An impact test is a test that measures the resistance of materials to shock loads. This is what differentiates impact testing from tensile and hardness testing, where the loading is carried out slowly. The purpose of this test is to see the effect of toughness, which is useful for seeing the effects caused by the presence of notches, notch shape, temperature, and other factors. The standard used in this research is ASTM E 23 with square cross-sectional dimensions of 10 x 10 mm with a V-45 notch, a base radius of 0.25 mm, and a notch depth of 2 mm. The dimensions of the impact test specimen are shown in Fig. 6 below.

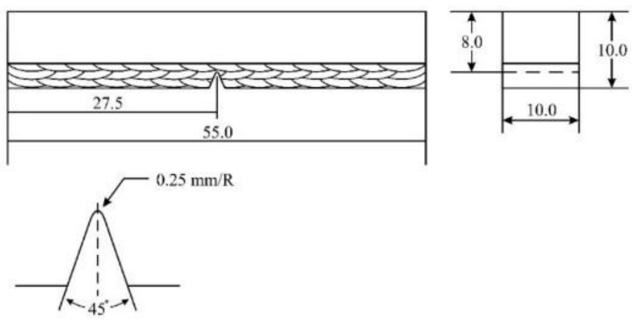


Fig. 6. Impact testing dimensions

Notches on the impact test specimen are made in the weld metal area. The position of this notch is determined to determine the toughness of the hardfacing welding in the weld metal area.

3. Results and Discussion

In this research, the hardfacing overlay welding process was carried out on ABREX 500 material with a welding current of 130 amps for each specimen. The results of welding carried out using 3 layers, 4 layers, and 5 layers can be seen in Fig.s 7 to 9, where specimen A is a specimen with 3 layers, specimen B is a specimen with 4 layers, and specimen C is a specimen with 5 layers.

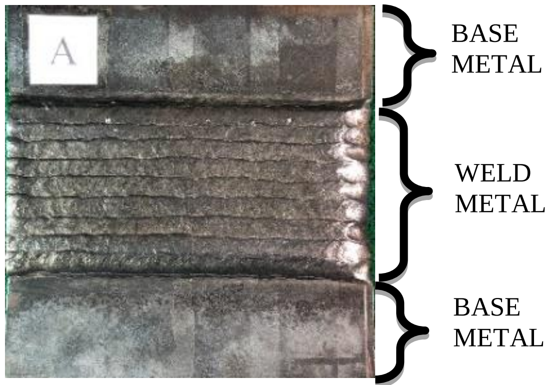


Fig. 7. layer welding results

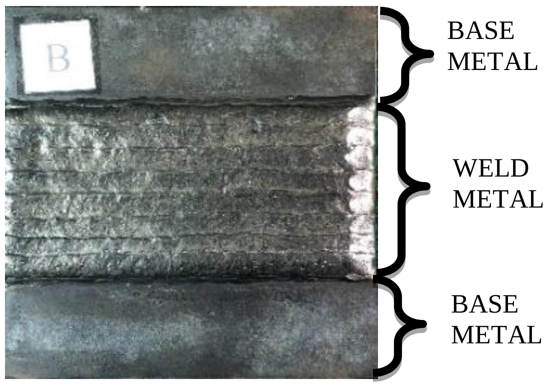


Fig. 8. Hasil pengelasan 4 layer

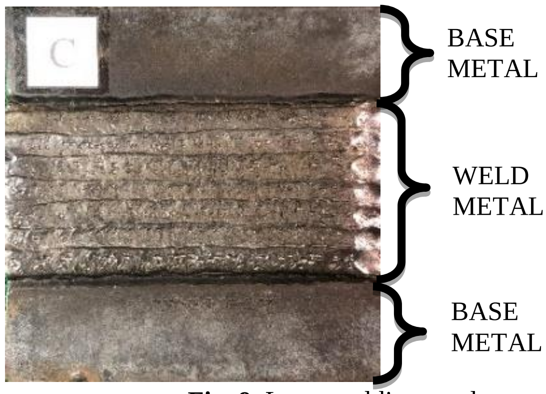
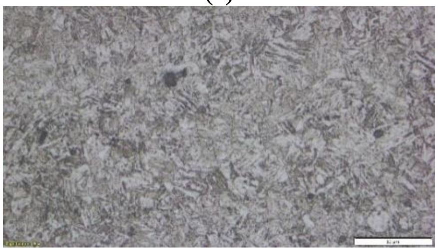


Fig. 9. Layer welding results

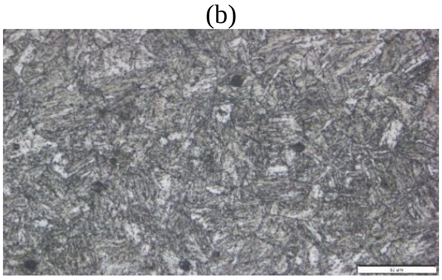
3.1 Pengujian *Metalografi*

Microobservations were carried out to determine what phases and structures are contained in the hardfacing overlay material. Microstructure observations were carried out on the base metal, buffer layer, and hardfacing layer for each variation with a magnification of 200x. The observed microstructure provides information about the mechanical properties and transformation processes that occur during welding until the liquid weld metal solidifies. The macrotest results for each specimen can be seen in Fig. 8 as follows:

(a)



(b)



(c)

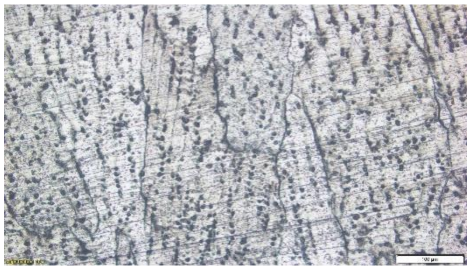
Fig.10. Base metal micro test results (a) welding with 3 layers, (b) welding with 4 layers (c) welding with 5 layers

Based on Fig. 11, it shows that the ABREX 500 material presents a previous tempered martensite structure that is comparable to the structure reported in the literature[9]. Due to the presence of a hard martensitic phase in its microstructure. Hardox 500 steel shows exceptional hardness, similar to the level of literature data[10]. Checking the microtest results on raw material specimens is the same as in the literature[11], as can be seen in Fig. 11.

Fig.11. Micro raw material test results

In specimens A to C, the microstructure that occurs in the base metal is full-tempered martensite, which is shown in the image and looks like broken glass. Tempered martensite occurs after the martensite undergoes a tempering process. The structure consists of martensite with coarser blades and small grains of carbide that experience precipitation. Bainite transformation occurs due to the rapid cooling rate. The fastcooling rate causes the austenite not to have enough time to transform into pearlite, so the structure formed is bainite. The microstructure of tempered martensite and bainite produces a high level of hardness and toughness, making it good for absorbing impact energy.

(a)



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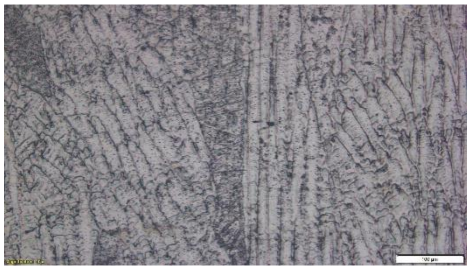
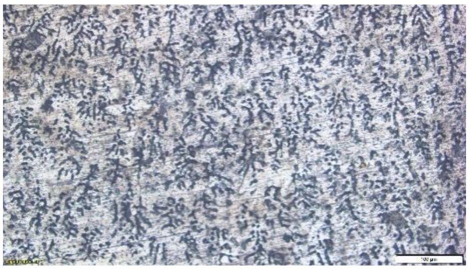


(c)

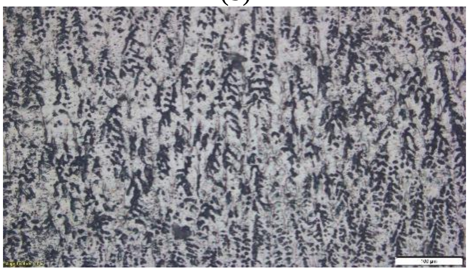
Fig.12. Micro Buffer Layer 1 Test Results (a) welding with 3 layers, (b) welding with 4 layers (c) welding with 5 layers

In the microtest results in the buffer layer 1 area shown in Fig. 12, austenite and vermicular ferrite microstructures were found. This is because the electrode used is austenitic stainless steel, namely the E309 electrode. The cooling of the liquid phase forms vermicular ferrite as the main phase. Vermicular ferrite is shown by dark-colored dendrites. When the temperature decreases, the outer part of the chromium-deficient dendrite forms austenite, and the chromium-rich rear part of the dendrite forms vermicular ferrite. At the end of cooling, the structures formed are austenite and ferrite. The structural properties of austenite tend to be softer and more ductile than those of ferrite, which is harder.

(a)



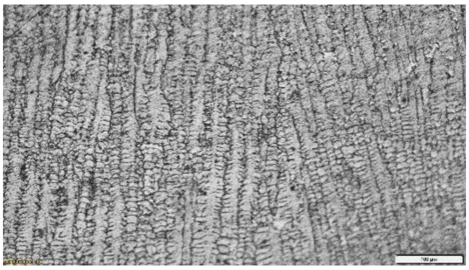
(b)



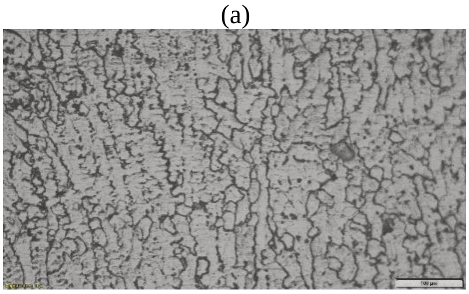
(c)

Fig.13. Micro Buffer Layer 2 Test Results (a) welding with 3 layers, (b) welding with 4 layers (c) welding with 5 layers

Not much different from the results of the microstructure in buffer layer 1, the results of microtesting in the buffer layer 2 area also found the microstructure of austenite and vermicular ferrite, as shown in Fig. 13. This is because the electrodes used in buffer layer 2 are the same as buffer layer 1, namely austenitic stainless steel, E309 electrode. It's just that there is a slight difference in the size of the vermicular ferrite structure; this is due to differences in the energy received, which can be in the form of heat input. The energy received in the buffer layer 1 area tends to be greater, so that the vermicular ferrite microstructure formed becomes larger and wider. This is inversely proportional to the layer 2 buffer area, which receives less energy, which causes the vermicular ferrite microstructure in the layer 2 buffer area to tend to be smaller and slimmer. And you can see the difference between using the number of layers 3, 4, and 5, where the vermicular ferrite in layer 5 is getting smaller compared to using 3 layers and 4 layers, which causes the hardness of buffer layer 2 using 5 layers to decrease.



(a)



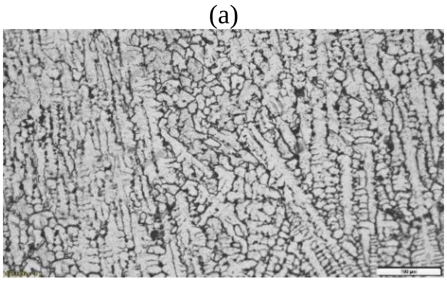
(b)

(c)

Fig.14. Micro hardfacing test results 1 (a) welding with 3 layers, (b) welding with 4 layers (c) welding with 5 layers

In the hardfacing layer 3 area shown in Fig. 14, the microstructure that occurs consists of pearlite and austenite in the form of dendritic segregation. This is the same as the pearlite structure, which is indicated by a dark color, while the austenite structure that is formed is very minimal and is marked by a lighter color. There is quite a lot of carbon in the HV600 electrode, which is an austenite former, causing the microstructure that occurs to be rich in austenite and its derivative, namely pearlite. The change of austenite to pearlite occurs when cooling occurs quite quickly. It is not much different from the microstructure that occurs in the three variables 3, 4, and 5 layers, which use a stainless steel austenitic buffer layer to form a dendritic phase between austeni, which appears light-colored and dark-colored pearlite. This dendritic shape occurs when the material experiences rapid cooling during the welding process, so that the liquid metal in the weld area freezes quickly and forms elongated dendrites. There is a difference in layer 3 hardfacing where the pearlite in layer 3 of specimens B, C, E, and F experiences a decrease in the pearlite phase, which increasingly disappears compared to the increase in layers in specimen A, whose pearlite structure looks more dense than specimens 2 and 3.

(a)



(b)

Fig.152. Micro hardfacing test results 2 (a) welding with 4 layers (b) welding with 5 layers

In the hardfacing area of layer 4 shown in Fig. 15, the occurring microstructure consists of perlite and austenite in the form of dendritic secretion. This is the same as the perlite structure shown in the dark color, while the austenitic structure formed is very minimal in the markedly brighter color. Like a decimal A, this decimal B has a closer perlite phase compared to the decimal C of layer 4, which has a perlite phase decrease.

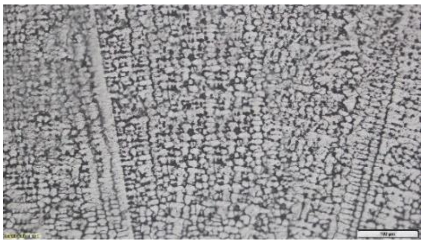


Fig.16. *Micro hardfacing test results 3 welding with 5 layers*

In the layer 5 hardfacing area shown in Fig. 16, the microstructure that occurs is the same as in the other hardfacing layers, consisting of pearlite and austenite in the form of dendritic segregation. Here you can see the difference in specimen C, which has a denser pearlite phase compared to specimens A and B in the top layer. With the increase in layers in specimens A, B, and C, the last layer experienced an increase in the pearlite phase structure, which was denser compared to the previous hardfacing layer. The phase decreased due to excessive heat from welding the hardfacing layer above it.

3.2 Hardness Testing

Hardness testing is carried out to determine the hardness value for each part in each process variation using the Vickers hardness testing method. Tests were carried out on cross sections of the specimen, which were carried out on the base metal, buffer layer, and hardfacing layer with an indentation distance of 1 mm. The loading used is 10 kgf with a dwell time of 15 seconds. Hardness testing was carried out at three points in each area. The following are the results of hardness testing on each specimen, which are shown in Table 1.

Tabel 1. Hardness test results

Area test	Test point	Hardness test value (kgf/mm²)
		Arus 130A
Base Metal	1	372.32
	2	380.63
	3	385.51
	Average	**379.48**
Layer 1	1	241.28
	2	245.60
	3	245.87
	Average	**244.23**
Layer 2	1	250.32
	2	251.52
	3	251.89
	Average	**251.24**
Layer 3	1	458.44
	2	454.82
	3	458.67
	Average	**458.61**
Layer 4	1	462.11
	2	469.82
	3	462.57
	Average	**464.83**
Layer 5	1	-
	2	-
	3	-
	Average	**-**

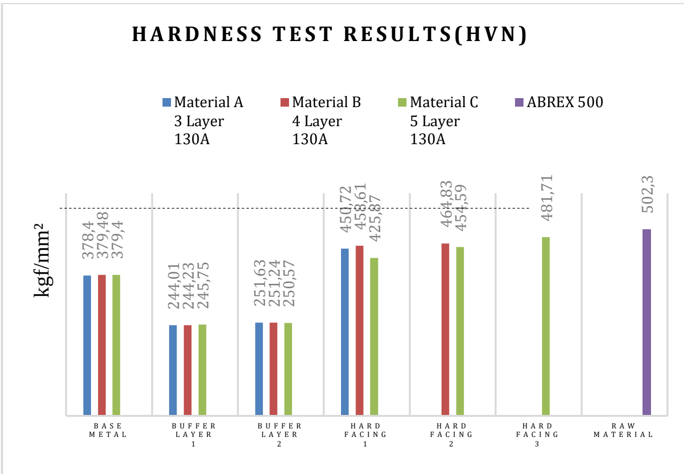


Fig.17. Graph of Hardness Test Results

Based on Table 1 and Fig. 17 of the hardness test results graph above, the hardness values for the base metal are relatively the same. The hardness value of the base metal decreases. This is caused by the heat that occurs during welding. Apart from that, the slow decrease in heat also affects hardness, so the hardness of the base metal decreases. The results of this study are the same as the results from the journal [12].

Several weld parameters influence the hardness value obtained. The material softens due to the input of heat, so the hardness is reduced. Apart from that, the hardfacing process is carried out using multilevel welding, where the amount of heat input for each level is different, causing different hardness at each level.

In the buffer layer 1 area, by using different numbers of layers, each specimen has an increase in hardness as the number of layers increases; the hardness of hardfacing welding using 3 layers is (244.01 kgf/mm^2), using 4 layers produces (244.23 kgf/mm^2), and welding 5 layers of hardfacing has a value of (245.75 kgf/mm^2).

In the buffer layer 2 area, when compared with the graph in the buffer layer 1 area, the hardness value for each specimen is not much different from the hardness value in the buffer layer. It's just that there is an increase in hardness from bufferlayer 1 to bufferlayer 2. The hardness value for bufferlayer 2 using 3 layers is (251.63 kgf/mm^2), for 4 layers the average value is (251.24 kgf/mm^2), and the average results for the use of 5 layers are (250.57 kgf/mm^2).

In specimens A, B, and C in the hardness test, the top layer, layer 3, layer 4, and layer 5 experienced an increase in hardness as each layer increased. The graph above indicates that the number of layers of 5 layers of hardfacing provides the optimum (highest) top layer hardness (481.71 kgf/mm^2) when compared to the number of other layers. In the hardfacing layer area, which uses HV600 electrodes with a hardness specification of 600 kgf/mm^2, there is a quite drastic decrease in the hardness of the electrode specs. This incident could occur due to the interpass temperature not being paid enough attention to. According to the results of the journal[13], other things are also caused by the use of buffer layers, as can be seen in the results of research[14].

3.3 Impact testing

Impact test results Impact tests are carried out to determine the toughness value of the material. This test was carried out in the weld metal area with a temperature of 20°C and specimen dimensions of 10 mm x 10 mm x 55 mm. The results of the impact test can be seen in Table 2 below.

Table 2. Impact Test Results

Variation	Specimen	Energy (J)	Impact Strength (J/mm²)	Rata-Rata (J/mm²)
3 Layer	A1	112	1,34	1,32
	A2	109	1,31	
4 Layer	B1	104	1,25	1,25
	B2	105	1,26	
5 Layer	C1	97	1,19	1,20
	C2	99	1,22	

From Table 2 and the graph in Fig. 18 above, it can be seen that there are differences in the impact values of each variation. Using layer variations also reduces the toughness value of the material. As layers increase, the toughness value will decrease. So the highest toughness value was obtained in specimen A, which used 3 layers with an impact value of 1.32 J/mm2. and the smallest toughness is in specimen C, which uses 5 layers with an impact value of 1.20 J/mm2. This is inversely proportional to the hardness value, where the hardness value will decrease when toughness increases and the material becomes ductile.

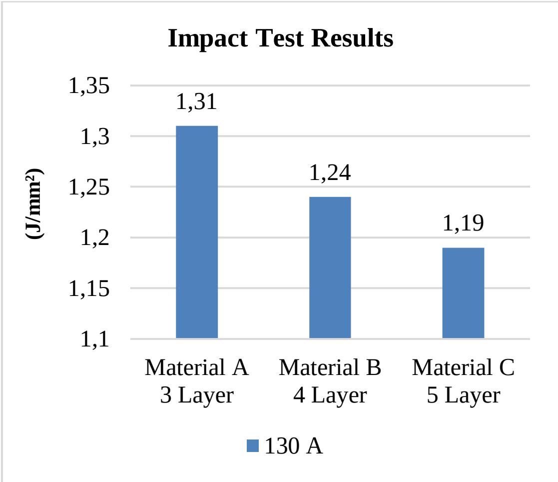


Fig. 18. Impact Test Results

4. Conclusion

From the research that has been carried out, the microstructure resulting from the ABREX 500 material overlay hardfacing process is quite complex. In the base metal part, the resulting microstructure is not much different, dominated by a tempered martensite structure. In the buffer layer area, the resulting microstructure is austenite and pearlite. In the hardfacing layer area, the resulting microstructure is in the form of a dendritic phase between austenite and vermicular ferrite. Judging from the research that has been carried out, it can be concluded that the number of layers used in the hardfacing welding process can influence the hardness and toughness values of the material when accepting loads. The highest hardness value in the uppermost surface area of the hardfacing occurs when 5 layers are used with a hardness value of 481.71 kgf/mm2. For toughness testing, the highest toughness value was obtained, namely 1.32 (J/mm2), in the 3 layers specimen, compared to the 4 layers with a toughness value of 1.25 (J/mm2) and the 5 layers with a toughness value of 1.19 (J/mm2). This is inversely proportional to the hardness value, where the hardness value will decrease when toughness increases and the material becomes ductile.

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[14] Rizqi, ”STUDI PENGARUH JUMLAH LAPISAN BUTTERING DAN JENIS ELEKTRODA TERHADAP SIFAT MEKANIS DAN KETAHANAN RETAK HASIL HARDFACING PADA BAJA TAHAN AUS CREUSABRO 8000 DENGAN PENGELASAN SHIELDED METAL ARC WELDING (SMAW),” p. 74, 2012.