Insights in Mining Science & Techonology
ISSN: 2689-4629

Review Article
Volume 3 Issue 3 - July 2022
DOI: 10.19080/IMST.2022.03.555612

Insights Min Sci technol

Hardfacing Technology: An Inevitable Technique for Development of Mineral Sector in Nigeria

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Submission: July 7, 2022; **Published:** August 02, 2022

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Abstract

Towards using hardfacing technology to achieve sustainable mining and mineral processing in Nigeria, a paper on the nitty-gritty of hardfacing is presented. Every State in Nigeria is endowed with one form of mineral or the other. Exploitation and processing to semi-finished and finished goods have been a herculean task. Malfunctioning of critical components due to wear and inadequate technical know-how for timely reparation or replacement have been the impediments to the development of the mineral sector; these have caused multiple downtimes, increased production cost and in some cases total shutdown. Capacity development in the areas of production of hardfacing alloys inserts, powders, stick, tubular and wire electrodes; use of known welding technologies such as plasma arc welding, shielded metal arc welding, flux cored arc welding, thermal spraying and cladding; and knowledge of hardfacing considerations like surface cleaning, composition compensation, hardfacing patterns, dilution minimization and avoidance of spalling are the key requirements for appropriate adoption and utilization of hardfacing technologies. Important steps that can be adopted towards developing the mineral sector in Nigeria have been outlined.

Keywords: Hardfacing alloy; Wear; Minerals; Welding; Substrate

Introduction

Nigeria is well endowed with varieties of strategic solid mineral resources that are widely distributed across the 36 states of the country. While the country is faced with the fundamental question of how to use its solid mineral resources to drive development in a sustainable way, mining activities in the solid minerals sector are largely dominated by small- and medium-scale miners who depend mainly on traditional mining practices. Wear of critical components of mining and mineral processing machineries has been the greatest challenge of the mineral sector in Nigeria. The bane of development of the abundant solid minerals in the country can be attributed to lack of technical know-how required for maintenance of machines used in the mineral sector.

There are over forty (40) solid minerals found to be in commercial quantities in Nigeria; some of the minerals are listed in figure 1[1]. Distribution of the minerals across the States is presented in table 1[2]. In mining and mineral processing industries, critical components of machineries are subjected to severe wear. Mechanical interactions between metal parts and between metals and abrasive nonmetallic and metallic ores result in significant wear of parts during extracting, handling, and processing of ores and stones. Malfunctioning of these parts due to wear has led to multiple downtimes, increased production cost and in some cases total shutdown. Moribund quarries and abandoned mineral processing plants have been linked to inability to replace important components such as crusher jaws and mantles [3,4]. A jaw crusher abandoned due inability to repair damaged corrugation is shown in figure 2.

Changes in the dimension and surface topography of a part due to wear can be regenerated using surface engineering techniques. Surface engineering or hardfacing aims at altering the microstructure and composition of the near surface region of the component without affecting the bulk of material to achieve the desired surface properties such as abrasion and corrosion resistance, thereby improving its function and service life [5,6]. The object of this paper is to unveil available and underexploited minerals and show how hardfacing technology can be used to achieve sustainable mining in Nigeria.

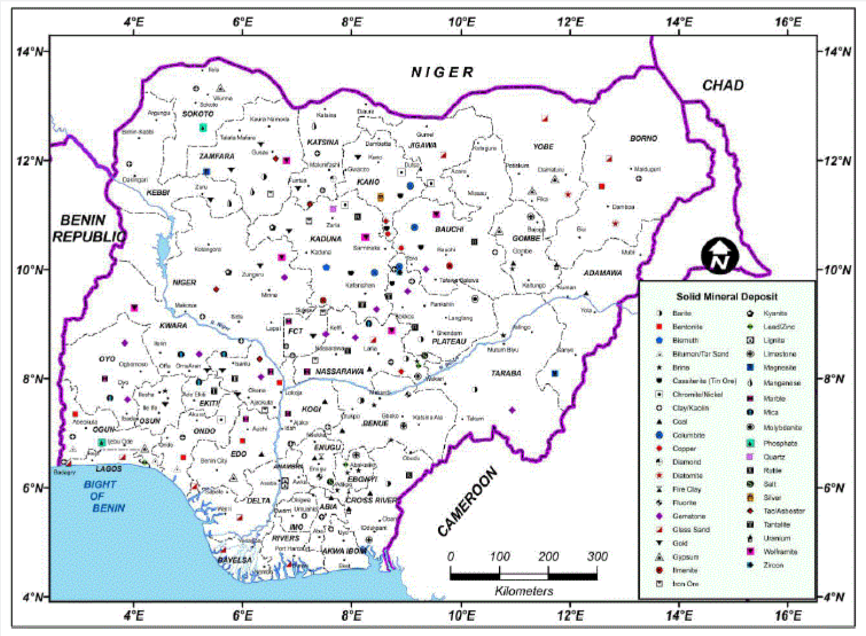

Figure 1: Solid mineral deposits in Nigeria [1].

Figure 2: Moribund jaw crusher in Jalingo quarry [4].

Nature of Hardfacing Alloys and Substrate Materials

The aim of hardfacing is to extend the service life of a worn critical parts or new hardfaced components. Usually, the electrode or filler metals with the same or close composition as the base metal is used to build-up the worn part or hardface tough substrate to form a new hardfaced component. Hardfacing alloys impart on existing surface properties such as abrasion resistance, surface hardness, impact resistance, hot hardness, erosion resistance and so on. Hardfacing alloys are categorized into:

I. low alloy ferrous materials (containing 2 – 12 % alloy constituent),

II. high alloy ferrous materials (containing 12 – 50 % alloy constituent),

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III. nickel-based alloys,
IV. copper-based alloys,
V. cobalt-based alloys,
VI. titanium-rich alloys,
VII. tungsten-rich alloys,
VIII. chromium-rich alloys,
IX. stainless steels, and
X. carbides [4].

Table 1: Minerals deposits distribution across States in Nigeria [1,2].

S/N	Minerals	States
1	Amethyst	Kaduna, Nasarawa
2	Aqua Marine	Kaduna, Oyo
3	Asbestos	Kaduna, Katsina
4	Barite	Benue, Cross River, Plateau
5	Bauxite	Plateau
6	Bentonite	Adamawa, Borno, Plateau, Akwa Ibom, Cross River
7	Bismuth	Plateau
8	Bitumen	Edo, Ogun, Lagos, Ondo
9	Cassiterite	Abuja, Bauchi, Kano, Kwara, Nasarawa, Oyo, Plateau, Kogi
10	Chalcopyrite	Nasarawa
11	Clay	Kaduna, Lagos, Ogun, Ondo, Oyo, Sokoto, Katsina, Rivers, Abuja, Akwa Ibom, Bauchi, Benue, Delta
12	Coal	Bauchi, Benue, Enugu, Kogi, Nasarawa, Ondo, Plateau, Zamfara
13	Columbite	Bauchi, Kwara, Nasarawa, Osun, Plateau, Gombe, Kaduna, Kano, Ondo, Benue, Kogi
14	Copper	Kano, Jigawa, Kano
15	Diatomite	Borno, Yobe
16	Dolomite	Abuja, Edo, Kogi, Nasarawa, Oyo, Kwara
17	Emerald	Nasarawa, Kaduna
18	Feldspar	Kogi, Kwara, Nasarawa, Ogun, Ondo, Borno, Ekiti, Katsina, Sokoto
19	Fluorspar	Kaduna
20	Galena-Lead, Zinc	Abuja, Akwa Ibom, Kaduna, Anambra, Bayelsa, Benue, Cross River, Ebonyi, Enugu, Kano, Gombe, Imo, Niger, Plateau, Taraba, Nasarawa
21	Gemstone	Benue, Gombe, Kaduna, Kano, Ogun, Ondo, Oyo, Plateau, Kogi
22	Glass-Sand	Anambra, Delta, Edo, Kano, Lagos, Ondo, Rivers, Akwa Ibom, Yobe
23	Gold	Abia, Abuja, Bauchi, Katsina, Edo, Kebbi, Kwara, Ekiti, Niger, Jigawa, Kaduna, Osun, Oyo, Sokoto, Zamfara
24	Granite	Ondo, Osun, Plateau, Ekiti, Yobe, Oyo, Taraba, Benue, Bauchi
25	Graphite	Kaduna, Katsina
26	Gypsum	Bauchi, Bayelsa, Benue, Borno, Delta, Imo, Kogi, Sokoto, Adamawa, Gombe, Kebbi, Yobe, Ebonyi
27	Iron ore	Anambra, Bauchi, Benue, Delta, Edo, Kogi, Borno, Kwara, Nasarawa, Plateau, Abia, Jigawa, Kaduna, Kebbi, Niger, Ondo, Oyo, Taraba, Enugu
28	Kaolin	Borno, Delta, Ekiti, Katsina, Kogi, Ogun, Plateau, Yobe, Abia, Abuja, Sokoto, Anambra, Enugu, Bauchi, Jigawa, Oyo, Ondo, Kano, Kebbi
29	Kyanite	Kaduna
30	Lignite	Akwa Ibom, Bauchi, Bayelsa, Cross River, Edo, Imo, Rivers, Abia, Sokoto, Delta

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31	Manganese	Cross River, Kebbi
32	Marble	Abuja, Benue, Delta, Kogi, Katsina, Kwara, Nasarawa, Oyo, Plateau, Rivers, Adamawa, Anambra, Edo, Yobe, Sokoto
33	Marcasite	Imo
34	Mica	Kaduna, Kwara, Nasarawa, Ekiti, Kogi, Zamfara
35	Molybdenite	Plateau
36	Phosphate	Anambra, Edo, Imo, Ogun, Sokoto
37	Potash	Sokoto, Borno, Kwara, Yobe, Jigawa
38	Quartz	Nasarawa, Jigawa, Kaduna, Kano, Ondo, Katsina, Kogi Ekiti
39	Ruby	Kaduna
40	Salt	Abia, Akwa Ibom, Anambra, Benue, Cross River, Sokoto, Ebonyi, Imo, Katsina, Nasarawa, Adamawa, Kebbi
41	Sapphire	Kaduna, Nasarawa
42	Serpentinite	Kaduna
43	Silica Sand	Sokoto, Edo, Rivers
44	Soda Ash	Yobe
45	Syenite	Ekiti
46	Talc	Kogi, Nasarawa, Niger, Osun, Oyo, Kaduna
47	Tantalite	Kaduna, Kano, Kogi, Nasarawa, Osun, Oyo, Plateau, Abuja, Bauchi, Benue, Ekiti
48	Tin	Plateau, Abuja, Bauchi, Gombe, Kaduna, Kano, Benue, Nasarawa
49	Topaz	Kaduna, Nasarawa
50	Tourmaline	Kaduna, Nasarawa, Osun, Jigawa
51	Uranium	Cross River, Adamawa, Taraba, Plateau, Bauchi, Kogi, Kano
52	Wolfram	Bauchi, Plateau, Benue, Nasarawa
53	Zircon	Nasarawa

Depending on area of application, hardfacing alloys are shaped in different forms such as stick electrodes, paste, insert, wire, tubular and powder hardfacing as shown in figures 3-8 [7-9].

Figure 3: Stick electrode.

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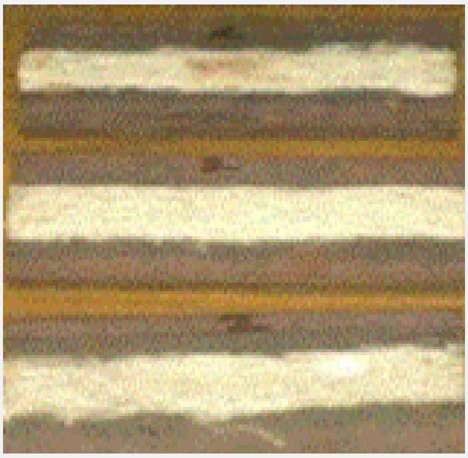

Figure 4: Hardfacing paste.

Figure 5: Hardfacing inserts

Figure 6: Tubular electrode.

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Figure 7: Hardfacing wire.

Figure 8: Hardfacing powder.

Substrates or base metals used in hardfacing are usually tough and can be categorized as follow:

I. low carbon steels, medium carbon steels,

II. high carbon steels,

III. low alloy steels,

IV. high speed steels,

V. medium alloy tool steels,

VI. high alloy steels,

VII. stainless steels,

VIII. manganese steels,

IX. low nickel chrome steels, and

X. cast iron [4].

Established Methods of Hardfacing

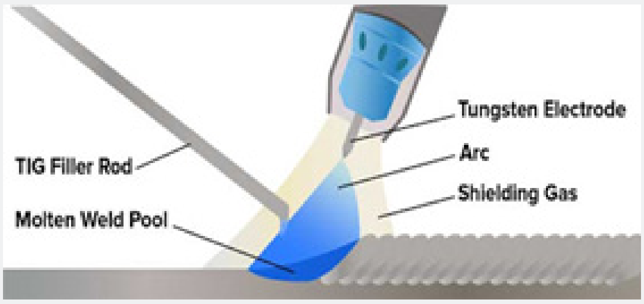

Figure 9: Tungsten inert gas welding [10].

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Most welding methods have been successfully used to apply hardfacing alloys on substrates. Examples of such hardfacing methods are depicted in figures 9-16 [10-17].

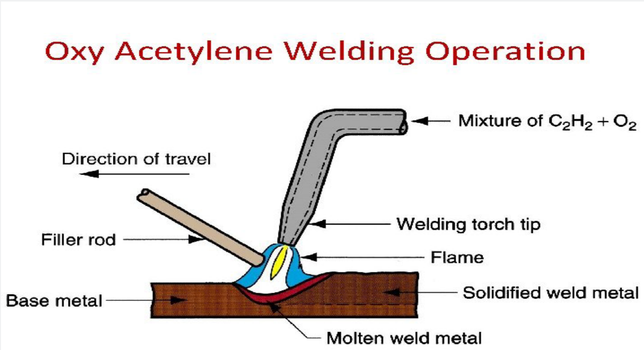

Figure 10: Gas welding.

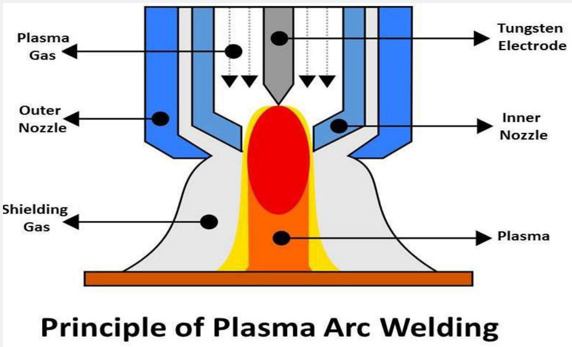

Figure 11: Plasma arc welding.

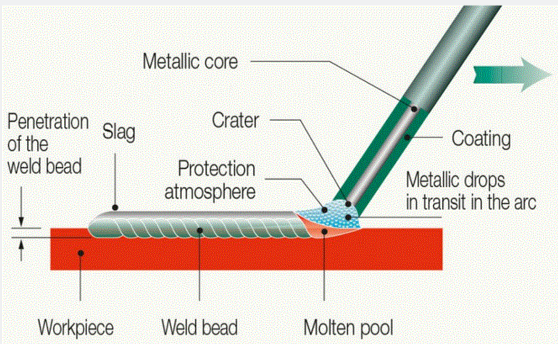

Figure 12: Manual metal arc welding.

Essential Considerations for Successful Hardfacing

Effective hardfacing of worn or new components can be achieved by ensuring the following:

I. Close composition between electrode or filler metals and the base metal is used to build-up the worn part.

II. Removal of grease, oil, paint, dirt, debris, and rust particles, from the surface of the substrate prior to hardfacing.

III. Compensating composition differences with a buffer material as shown in figure 17 [18], to avoid spalling.

IV. Minimal dilution that will guarantee strong bond

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between the base metal and the hardfacing alloy interface as shown in figure 18 and tabulated in table 2 [19,20].

V. Calculation of the carbon equivalent and preheating temperature of the substrate using its composition and thickness as presented in equations 1 to 3.

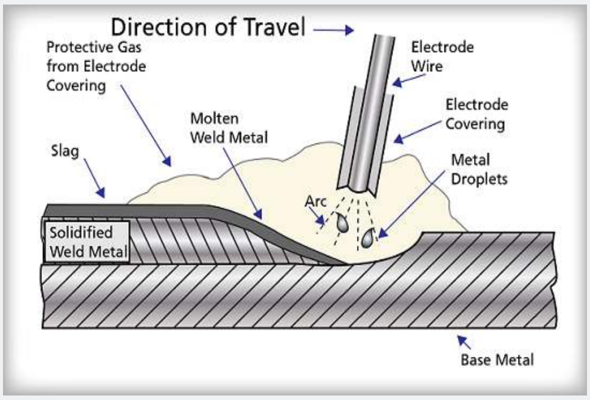

Figure 13: Shielded metal arc welding [14].

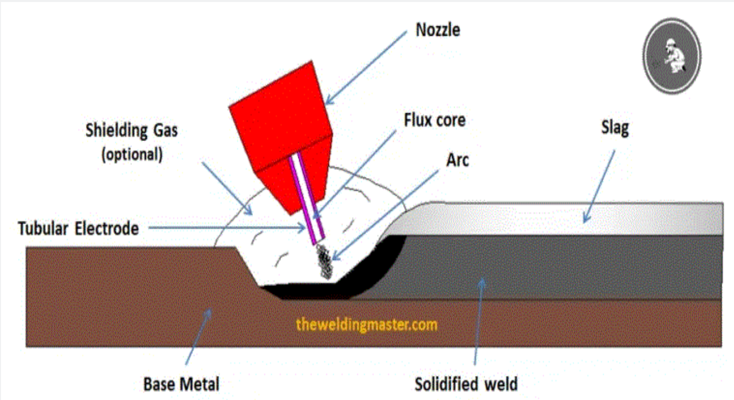

Figure 14: Flux cored arc welding [15].

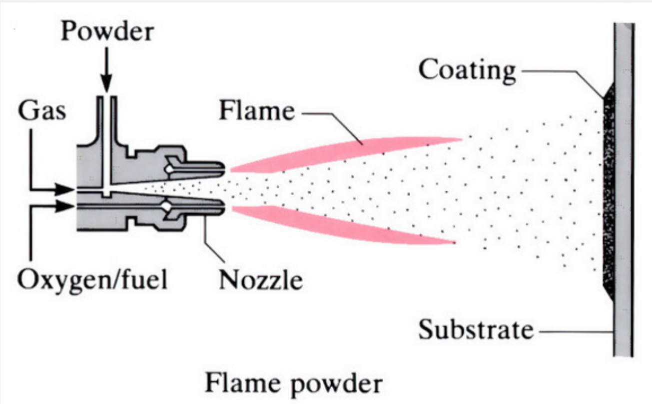

Figure 15: Thermal spraying [16].

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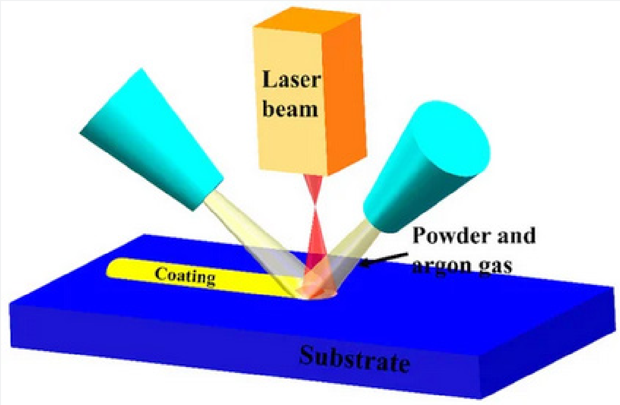

Figure 16: Laser cladding [17].

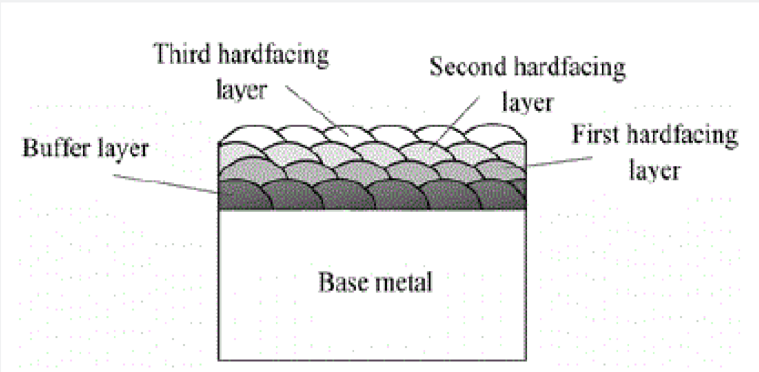

Figure 17: Buffer in hardfacing [18].

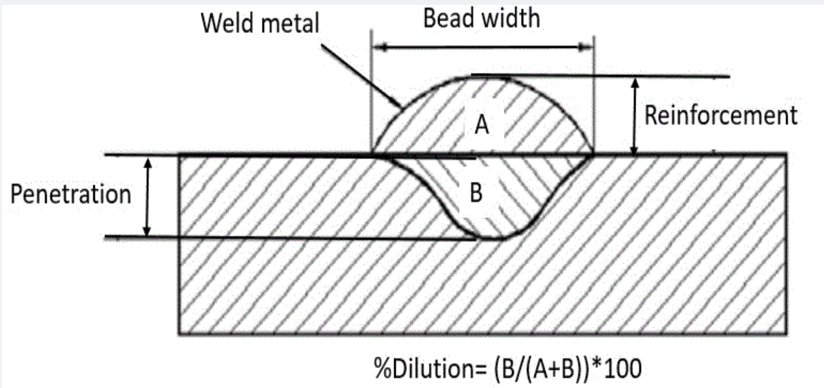

Figure 18: Dilution in hardfacing [19].

The composition of the low carbon steel plate can be determined with spectrometer and the carbon equivalent (CE) calculated therefrom; the CE can be determined with a carbon equivalent analyzer or from CE values for carbon steels from standard tables; while the preheating temperature T_p is calculated with the aid of the Seferian formulae presented in equations (1) to (3):

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$$T_p = 350.\sqrt{Ce - 0.25}, \text{°C} \quad (1)$$

$$Ce = CE(1 + 0.005.S_b), \% \quad (2)$$

$$CE = C + \frac{Mn + Cr}{9} + \frac{Ni + 7Mo}{18}, \% \quad (3)$$

where, Ce is a function of the carbon equivalent and thickness of the substrate, CE is the chemical carbon equivalent, and S_b is the thickness of the substrate [21]. If some elements in the CE formula are not present in the steel, their values zero out; also, when elements that are not present in equation (3) are found, appropriate CE formula containing those elements are used [4]. Other important consideration during hardfacing includes the hardfacing pattern to be used in different environments; these include:

VI. Dot hardfacing. This is used in areas that do not experience heavy abrasion or remote areas that are difficult to reach, as depicted in figure 19.

VII. Stringer hardfacing: This hardfacing pattern is divided into two, viz:

Horizontal stringer bead hardfacing is used when handling smaller-grained materials placed perpendicular to the flow of materials as presented in figure 20. Vertical stringer bead hardfacing is used when large-grained materials are placed parallel to the direction of flow of materials as presented in figure 21.

VIII. Waffle/ Crosshatch hardfacing pattern. This is used when working on soil containing clay as shown in figure 22. This pattern traps the soil and protects the surface underneath.

IX. Shape of hardfaced surface must be considered as some shapes may exacerbate failure of hardfaced component.

Okechukwu [4] showed that by simulation of virtual hardfaced crusher jaw, semicircular corrugation is better than triangular corrugation because of the former's lower Von Mises stress and equivalent strain as shown in figures 23-28.

X. Avoid spalling, which occurs due to much penetration of the hardfacing layer into the substrate as shown in figure 29 [4]. This can be prevented using a buffer on the substrate before applying the hardfacing layers as presented earlier in figure 17.

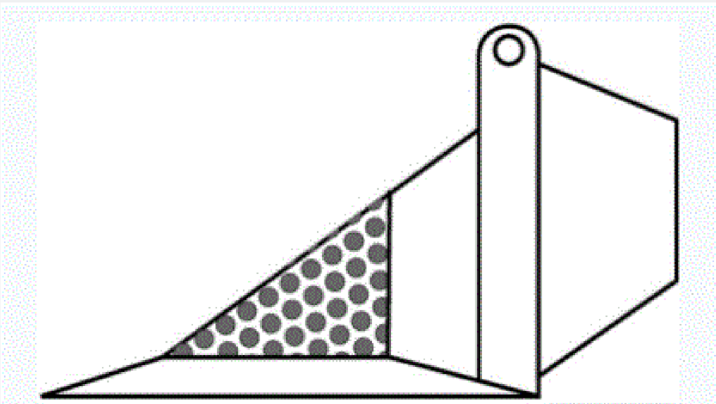

Figure 19: Dot hardfacing [8].

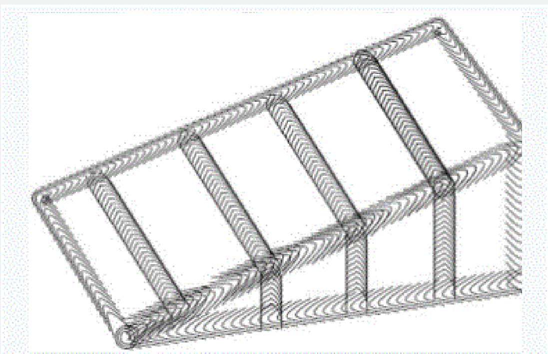

Figure 20: Horizontal stringer bead hardfacing [8].

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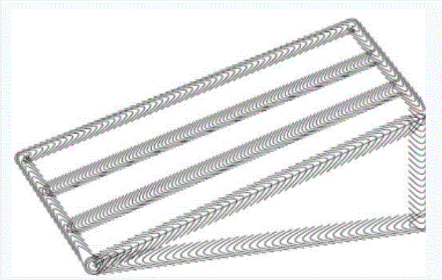


Figure 21: Vertical stringer bead hardfacing [8].

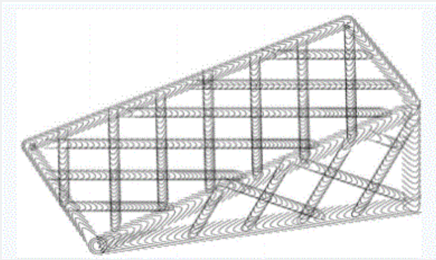
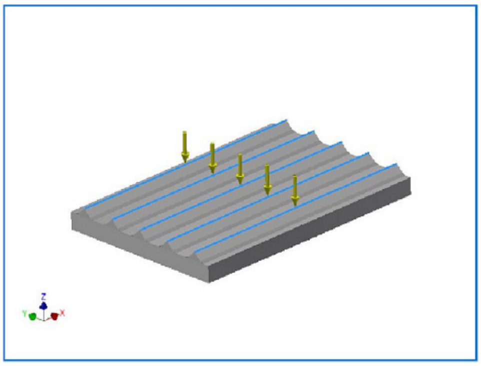
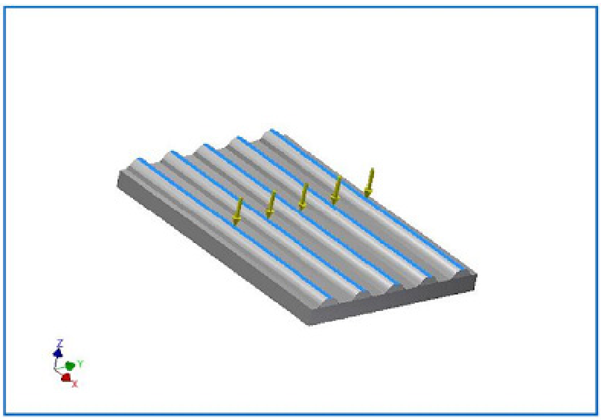


Figure 22: Waffle hardfacing [8].



Load Type	Force
Magnitude	1683.620 N
Vector X	-0.000 N
Vector Y	0.000 N
Vector Z	-1683.620 N

Figure 23: Crushing force applied on triangular AISI 6150 steel corrugations.



Load Type	Force
Magnitude	1683.620 N
Vector X	-0.000 N
Vector Y	0.000 N
Vector Z	-1683.620 N

Figure 24: Crushing force applied on semicircular AISI 6150 steel corrugations.

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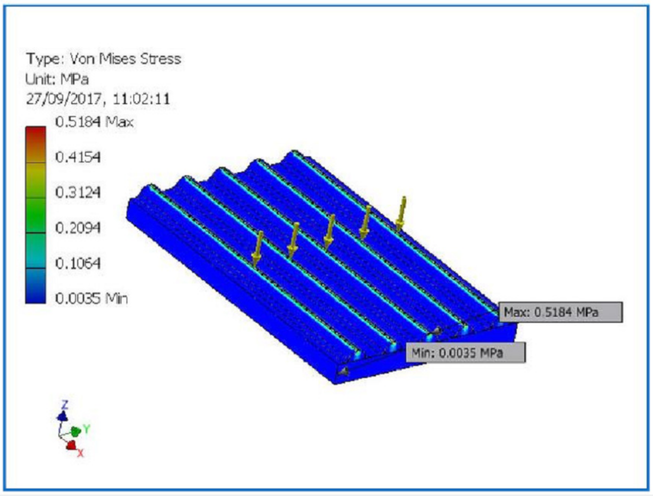

Figure 25: Von Mises stress for the semicircular corrugation.

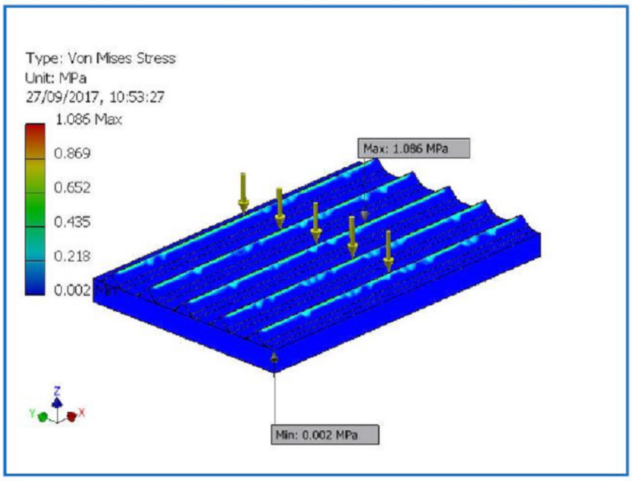

Figure 26: Von Mises stress for the triangular corrugation.

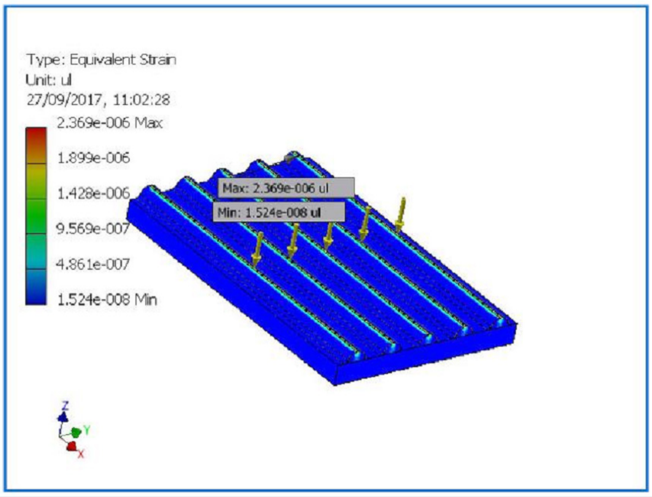

Figure 27: Equivalent strain for the semicircular corrugation.

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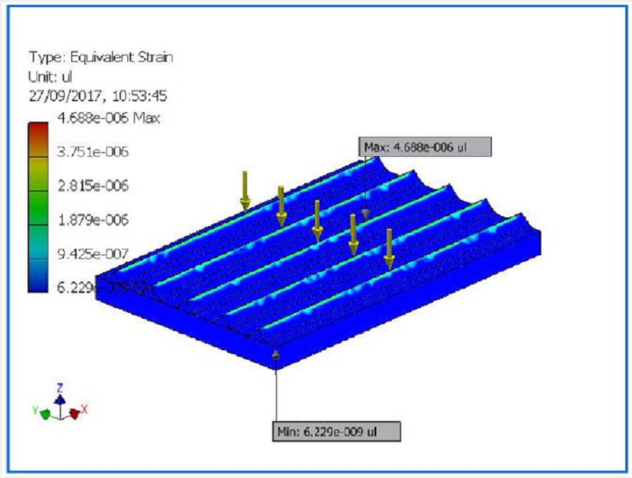

Figure 28: Equivalent strain for the triangular corrugation.

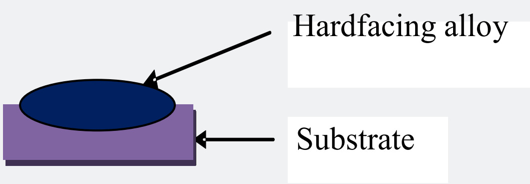

Figure 29: Spalling in a soft substrate.

Table 2: Dilution factors for some welding processes [20].

S/N	Welding Processes	Dilution Factors (%)
1	Oxy-acetylene gas welding	0 – 5
2	Tungsten inert gas welding	5 – 15
3	Shielded metal arc welding	20 – 45
4	Flux cored wire arc welding	20 – 45
5	Submerged arc welding	25 – 50

Pertinent Steps to Developing the Mineral Sector in Nigeria

Towards development of the mineral sector using hardfacing technologies, the following steps will fast-track the attainment of sustainable mining and mineral processing status in Nigeria.

I. Development of hardfacing alloys in the form of inserts, wires, powders, stick, and tubular electrodes using powder metallurgy, casting, atomization, pulverizing and agglomeration techniques.

II. Production of new critical components of mining and mineral processing machineries using available ferrous-based substrates e.g., low carbon steel and cast iron.

III. Reparation of worn-out critical components of machines used in the mineral industries. This can be extended to construction, agriculture, process, and food industries.

IV. Establishment of start-up hardfacing companies with requisite training on wear identification, hardfacing alloy production, welding, and hardfacing procedures.

V. Creation of linkages between start-up companies and industries requiring hardfacing services. Such industries include mining, mineral processing, quarrying, construction, cement, sugar, steel industries and railway corporation.

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VI. Manpower training on hardfacing techniques such as thermal spraying, sintering, laser cladding and other welding techniques.

VII. Acquisition and reverse engineering of hardfacing equipment and machineries.

VIII. Development of mining and mineral processing machineries and their critical components using hardfacing technologies [22].

Conclusions

Mineral endowment of Nigeria is being underexploited and underutilized for the development of the country. Moribund mining and mineral processing facilities abound in the country due to inadequate knowledge of techniques for timely repair or replacement of worn critical components. Production of hardfacing consumables in form of stick electrodes, paste, insert, wire, tubular and powder hardfacing and selection of appropriate substrate are important towards ameliorating various types of wear. Most known welding methods are being used for hardfacing.

Use of suitable hardfacing patterns, surface enhancement techniques, hardfacing-alloy-substrate composition, joining method, buffer, percentage dilution and substrate preheating temperature will go a long way in achieving sound hardfacing. Lower equivalent strain and Von Mises stress under the same force condition have been used to select semicircular corrugation over triangular corrugation in critical wear resistant components such as hardfaced crusher jaws.

Other technologies that go with hardfacing include powder metallurgy, casting, atomization, pulverizing and agglomeration techniques. To attain sustainable mining and mineral processing in Nigeria, these technologies should be domesticated for the purpose of producing hardfaced wear resistant components and timely replacement or repair of worn machine parts.

Conflict of Interest

We hereby declare that there is no economic interest or conflict of interest in our work.

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How to cite this article: Haruna MS, Dahunsi OA, Okechukwu C, John CT. Hardfacing Technology: An Inevitable Technique for Development of Mineral Sector in Nigeria. Insights Min Sci technol.2022; 3(3): 555612. DOI: 10.19080/IMST.2022.03.555612

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How to cite this article: Haruna MS, Dahunsi OA, Okechukwu C, John CT. Hardfacing Technology: An Inevitable Technique for Development of Mineral Sector in Nigeria. Insights Min Sci technol.2022; 3(3): 555612. DOI: 10.19080/IMST.2022.03.555612