Effect of Various Process Parameter of GTA Cladding on Surface Properties of Mild Steel: A Critical Review

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Abstract. Mild steel has considerable importance in the field of engineering due to its high strength, good mechanical properties and low cost. However, its application is restricted in some industries where wear failure is considered as major problem. Wear attacks on the moving components from the upper surface, which proves wear is often a surface phenomenon. Many researchers have used the gas tungsten arc (GTA) cladding process to deposit a thick alloy layer, metal matrix composite layer and ceramic composite layer on low carbon steel substrate due to its high deposition efficiency, inexpensive, easy to operate and good performance. The metal matrix composite (MMC) coating makes the components reusable because of the synergetic effect of the combination of hard reinforcement and ductile matrix. Researchers also investigated that the deposition of hard coating synthesized by the in-situ method gives better properties rather than the ex-situ method due to the mismatch of the wetting properties between the various phases of ceramics materials during the ex-situ method. This review paper summarizes the literature related to the GTA cladding on mild steel and its applications. Further, it was also described here about the effect of coating materials, process parameters of GTA cladding on surface properties of mild steel such as resistance to wear, corrosion resistance and hardness. This review paper will provide reference for the researchers working in the GTA cladding area.

Introduction

In many industries, mild steel components have been used in various conditions such as high speed, load, chemical condition and elevated temperature or combination of these. Due to high strength, toughness and relatively low coast of the mild steel, it is frequently used for structural engineering components. However, it is restricted to use mild steel in some industries because of its miserable surface properties such as wear, corrosion, oxidation resistance and microhardness [1-3]. Thus, a surface treatments technique required to enhance surface properties of the mild steel. There are three different surface treatments available for steel such as thermal treatments, thermo-chemical treatments and surface coating. Thermal hardening such as flame and induction hardening, enhance the surface properties by modifying microstructure without altering its surface chemistry. This method is not suitable for mild steel. Thermal hardening is restricted to use on the steel that have carbon content less than 0.5 % [4]. Thermo-chemical treatments such as carburizing, boriding and nitriding, improve the surface properties by modifying microstructure as well as surface chemistry of the steel. It modify the surface properties and tribological properties of steel. This process also restricted to use due to processing on very high temperature and high case depth. Due to processing at high temperature can occurs oxidation on the surface and distortion of the steel components [5-6]. Surface coating involves melting of the coating powder with preferable composition and thin substrate surface deposition of dense coating layer on the substrate [7]. There are various surface coating process such as physical vapour deposition (PVD), chemical vapour deposition (CVD), cladding by electron beam, laser beam coating, gas tungsten arc (GTA) coating/cladding, plasma arc coating and thermal spraying. Among these surface coating techniques, GTA coating gained much attention due to following advantages such as easy to operate, abundance availability and low cost [8]. It not only provide better microstructure and tribological as well as surface properties but also remarkably improved the powder utilization as well as cladding efficiency [9].

Numerous researchers improve the surface properties of the substrate by depositing the various types of ceramic composite and metal matrix composite by GTA cladding. Metal matrix composite provides the combination of the properties of metals (soft phase) as well as ceramic reinforcements (hard phase) that are not provide by a single ceramic reinforcement materials. Many authors reported about the various metal matrix composite such as Ni–TiC-TiB_2, Fe–Al_2O_3–TiB–TiN, Fe–TiB_2–TiN–BN, Al_2O_3–TiB_2–TiC etc [10-12].

Wear and corrosion is the failure mode of the mechanical components that working under moving condition and chemical environment. Coating of the base metal is one of the most effective idea to restrict the corrosion as well as wear of the base metal. Coated layer provide the obstacle between the base metal and environment in the existence of corrosion or chemicals. For providing adequate protection against wear and corrosion, coating layer should be free of voids or pore, uniform layer and well adhered. Coating successfully increases the service life of the components by providing high wear resistance and corrosion resistance to the components [13, 14].

The purpose of the present study is to collect the information about GTA cladding on mild steel. This paper also demonstrate the effect of the various process parameters of GTA cladding and coating materials on the microstructure of the coating and properties of the coated materials such as microhardness, wear resistance and corrosion resistance. Authors explored the feasibility of deposition of crack and pores free GTA coating on the mild steel substrate.

GTA cladding process

Gas tungsten arc cladding process has been used for depositing the coating layer on the mild steel. In this process, non-consumable tungsten electrode used to accomplish the heating to melt the preplaced layer and substrate surface simultaneously. The schematic diagram of GTA cladding on the mild steel substrate shows in Fig. 1. It also shows the coated tracks, preplaced layer as well as passage for shielding gas in the GTA nozzle.

During cladding the clad zone is protected by the use of shielding gas such as argon gas, nitrogen gas etc. [15]. The tool travel speed controlled by the automatic GTA cladding or use of moving machine attached with torch holding device. A flow chart shown in Fig. 2 that show the deposition of coating on the mild steel substrate using GTA coating technique.

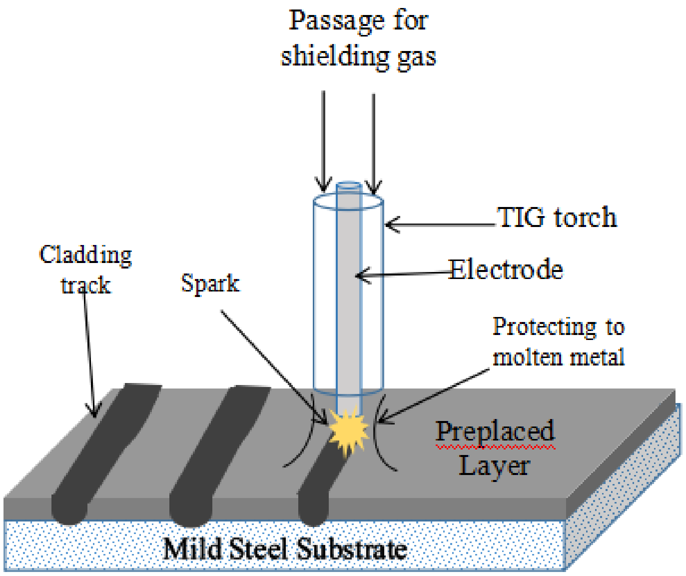


Fig 1. The setup diagram of the gas tungsten gas (GTA) cladding

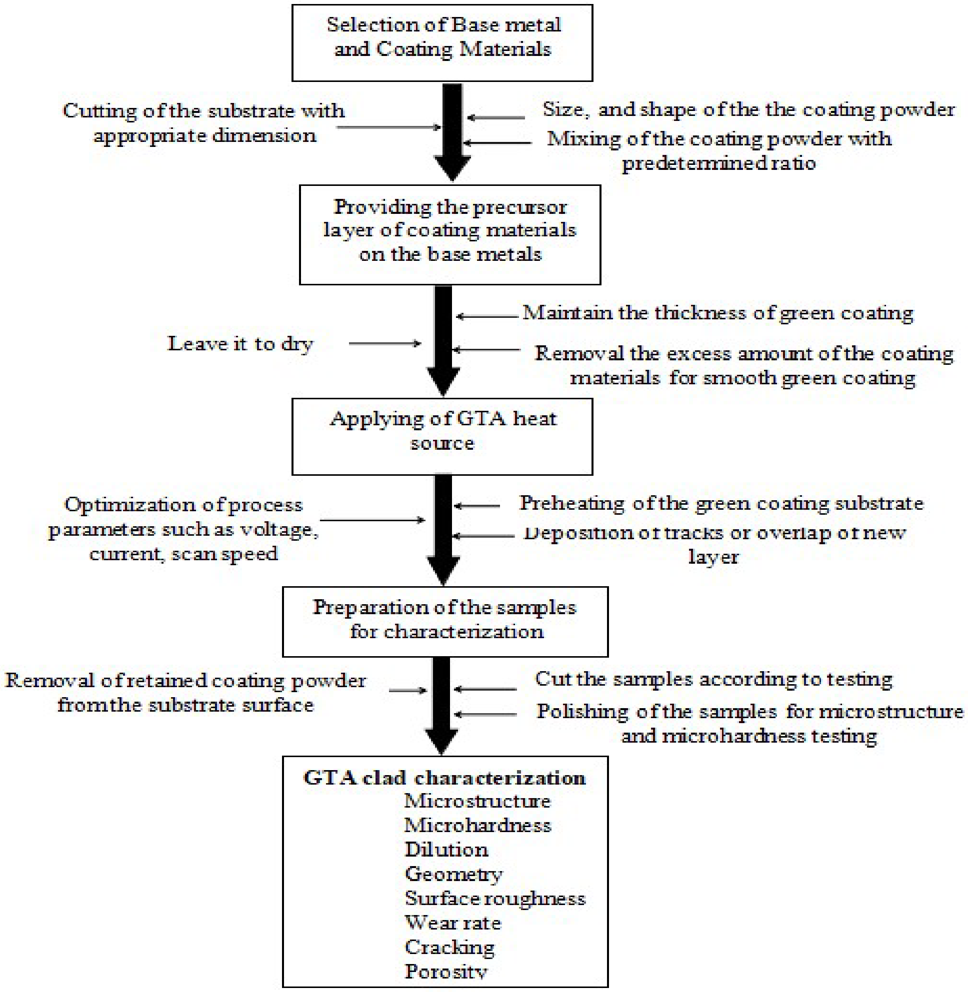


Fig. 2 Flow chart of deposition of coating layer using GTA cladding

Influence of process parameters of GTA cladding on surface properties of mild steel

Numerous researchers have deposited the coating layer on the mild steel using GTA cladding and have reported the influence of process parameters of GTA cladding such as input current, voltage, scan speed, shielding gas, different coating materials etc. on the surface properties of mild steel.

Shielding gas

During gas tungsten arc (GTA) cladding, different type of shielding gas used such as argon, nitrogen, carbon dioxide (CO_2) to shield the molten metal from the environment. The shielding gas is a factor that directly affect the microhardness and quality of coating layer. Hojjatzadeh et al. (2012) deposited the ferrotitanium coating layer on AISI 1045 steel with shielding gas of 100%N_2, 70%N_2–30%Ar, 40%N_2–60%Ar, 20%N_2–80%Ar and 100%Ar using GTA cladding. Authors noticed that the increasing of nitrogen content with argon shielding gas promoted the arc voltage therefore the heat input also increases. This high specific heat input directly enlarged the cross section area and penetration depth as show in Fig. 3. High amount of nitrogen gas in the shielding gas promoted the larger dilution of the substrate that leads to decreases in hardness value of coated samples.They also noticed that the porosity observe on the outer layer of the coating with high contents of nitrogen and eliminated with less than 40 % nitrogen content [16].

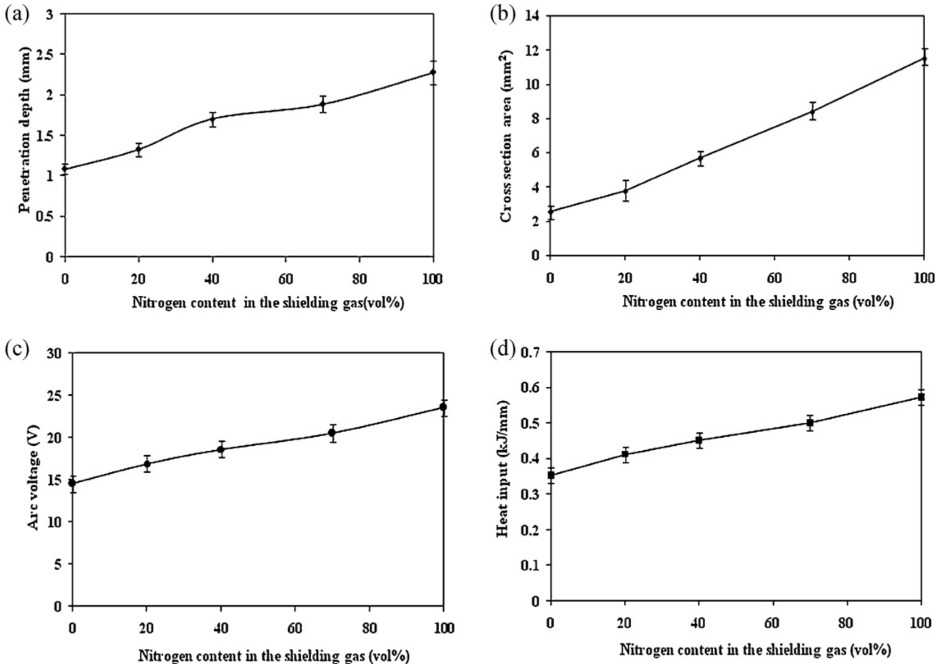


Fig. 3 Influence of nitrogen gas content on the (a) depth of penetration of the tracks, (b) cross section area, (c) arc voltage of GTA cladding and (d) GTA heat input during coating [16]

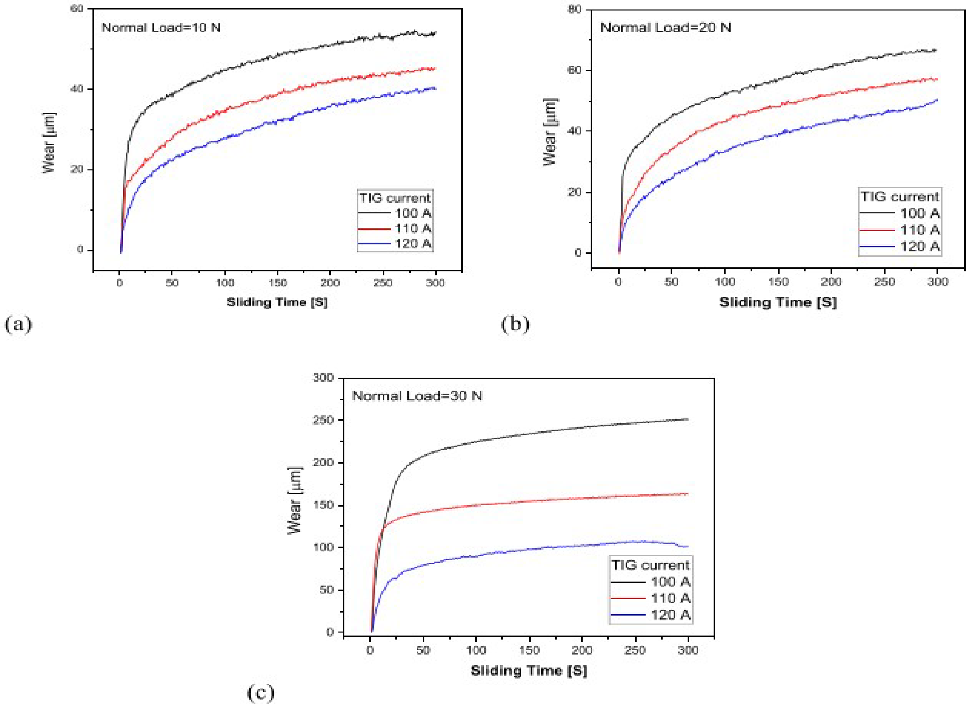
Huang (2009) also investigated the effect of nitrogen increment in the shielding gas with and without activating flux on properties of GTA weldments. They reported that the heat input promoted with increasing the nitrogen content in the protecting gas therefore penetration depth increases [17]. Dyuti et al. (2010) also synthesized the TiAlN cladding by TIG cladding on mild steel substrate using pure nitrogen shielding gas. It was noticed that some pores also present in the nitrided layers [18].

Input current and voltage of GTA cladding

The GTA cladding utilized to melt the preplaced layer and substrate surface and deposit a new layer on the substrate. The heat input of GTA cladding depends upon the input current, voltage and torch scanning speed. The heat input calculated by the following formula [19];

$$\text{Heat Input} = (0.48 \times \text{current} \times \text{voltage}) / (\text{scan speed}) \quad \ldots\ldots.. \quad (1)$$

Dyuti et al. (2010) deposited the Ti and Al composited coating on the mild steel substrate using different heat input of TIG cladding. It was found that the melt of the coating depends upon the heat input as well as voltage and current of TIG. Glazing directly depends upon the current and voltage whereas inversely proportional to torch speed of the TIG . At high scan speed reduced the glaze time therefore small melt depth occurs. The fine dendrites formed close to substrate surface in random direction because of fast solidifying of the melt pool. The glazing at high energy density the excess melting of base metal occurs and decreases the titanium-aluminum nitride particles in the coating zone. The microhardness achieved was maximum near the surface of the coating glazed with lower heat input [18]. Komvopoulo et al. (1990) reported that at the top surface of the coating fine microstructure was achieved because of high solidification rate in case GTA cladding as a result hardness and wear resistance of the substrate improved [20]. Sekhar et al. (2020) deposited the pure TiC composite coating on mild steel at different processing current. Authors noticed the major effect of the current on the hardness as well as wear loss value. It was reported that the maximum hardness value achieved about 3000 HV at 100 A and decreases with increases above 100 A processing current due to dilution of the mild steel with TiC coating layer occurs at high heat input. Due to high heat input (at 110 A and 120 A) melting depth increases due to dilution occurs. It was reported that the wear loss decreases with increasing processing current due to improvement of the bonding between TiC particles and steel substrate as shown in Fig. 4 [21].



(a) (b)

(c)

Fig. 4 Wear rate of the pure TiC coating layer with increasing input current at various applied load (a) 10 N, (b) 20 N and (c) 30 N [21]

Das et al. (2020) had improved the microhardness of AISI 1020 mild steel with Fe-based composite coating using TiC ceramic particles deposited by TIG cladding. It was reported that the microhardness value was maximum at 140 A, and decreases further with increase in input current [22].

Coating materials
The surface properties of the mild steel are enhanced by depositing the cladding layer using desirable coating materials by the GTA cladding techniques. The composite coating can be deposited by either directly mixing of ceramic materials such as TiN, TiB_2, SiC, TiC, WC etc. or hard phase produced in-situ techniques such as Ti + B_4C formed TiB, TiB_2 and TiC composite coating.

In recent years, the Ni-based coating possesses excellent advantages such as providing good bonding between coating materials and substrate, reducing friction coefficient, increasing wear and corrosion resistance. Among various ceramic reinforcements TiB_2 and TiN are considered as excellent ceramic materials because of its high melting points, excellent hardness and high thermal stability. Meng and Ji (2013) synthesized the TiN-TiB_2 ceramic phases in Ni-based coating layer on 16 Mn steel by in-situ process using arc cladding process. Researchers carefully analyzed the microstructure of the sample and noticed the TiB_2 (hexagonal and rectangular in shape) distributed in top surface of the coating, TiN (near spherical shape) distributed in middle zone and very less amount of TiN and carbide particles distributed in bottom zone. It was reported in the study that the microhardness gradually decreases with distance from the top surface of the coating and maximum microhardness found in the spam of 1100-1380 $HV_{0.2}$ [23].

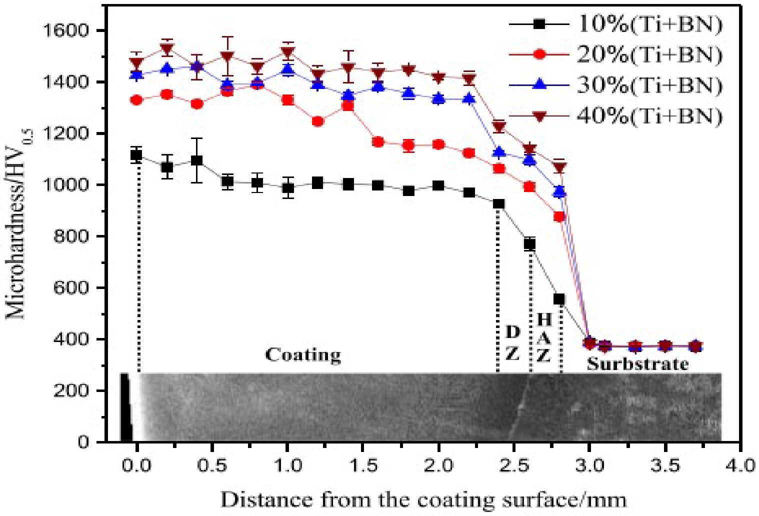


Fig. 5 Microhardness distribution of the composite coating with different composition of Ti+BN [24].

Meng et al. (2019) evaluated the wear and friction properties of Ni based composite coating using Ti and BN coating powder on a low carbon steel substrate. From XRD analysis of coated samples, it was noticed that the diffraction peak of TiB_2 and TiN increases with increasing the BN + Ti contents. Therefore microhardness of the composite coating enhanced with increasing of BN and Ti contents due to the increasing number of TiN and TiB_2 phases in coating zone. Researchers reported four regions: coated zone, dilution region, heat affected zone (HAZ) and substrate as show in Fig. 5. The microhardness achieved was in the range of 1100–1500 $HV_{0.5}$ in coating zone. The wear loss of the composite initially decreases up to 30 % of Ti+BN and then increases with more than 30 % of Ti+BN contents [24].

Ceramic materials such as TiB_2, TiC, and Al_2O_3 and combination of these enhance the resistance to mechanical wear, hardness and chemical stability. Wang and Du (2010) improved the wear resistance and hardness of AISI 1020 steel by depositing the Fe based TiC-TiB_2-Al_2O_3 ceramic composite using GTAW process. The Al_2O_3 and Ti formed at 1025 °C because at this temperature exothermic reaction take place between Al and TiO_2 while TiC-TiB_2 formed at 1100 °C due to reaction take place between Ti and B_4C. The microhardness of the composite coating approaches about 1700 HV. From the wear test analysis, they reported that because of the formation of TiB_2-TiC-Al_2O_3 ceramic phases the quality of coating improved and enhance the plastic deformation resistance [25]. Sharifitabar et al. (2016) deposited the Fe–TiC–Al_2O_3 composite by GTA cladding on the AISI 1045 steel substrate using TiO_2–Al–C–Fe coating powder. It was reported in his that the coating with 0Fe approach minimum 430 HV while coating with 20Fe50C achieved maximum hardness value about 830 HV because of the TiC and Al_2O_3 particles detected after solidification in the coating layer. The researchers also tested the wear behaviour of samples with 20Fe50C and base metal using 5 N and 10 N normal load and reported that the wear resistance of the coated sample (20Fe50C) better than the base metal and did not affected by the change in normal load [10]. Weng et al. (2006) produced the Fe based TiC composite coating on the mild steel using graphite and ferrotitanium (FeTi) by GTA cladding. The microhardness test was also performed of the coated samples and maximum hardness value achieved was between 700–800 HV [26]. Tekera et al. (2014) have enhanced the wear resistance and hardness of AISI 1020 mild steel using different mixture of Hardox 450 steel and FeB powder. The microhardness value increases with boron content increases in mixture of composite powder. It was found that more B_8C and Fe_3B phases were present in the coating layer with 40 % FeB ($S_{2.4}$) therefore maximum hardness values measured as 655 HV for sample this samples. Wear resistance found excellent for the $S_{2.4}$ as compare to other samples [27]. Zhen-ting et al. (2008) synthesized in-situ TiC-TiB2/Fe based coating on steel substrate using argon arc cladding process. It was investigated and reported that the wear resistance and microhardness enhanced with increase the Ti+B_4C coating powders contents becuse the synthesis of the TiB_2 and TiC phases in the coated layer [28]. Xinhong et al.used the graphite, ferrotitanium and ferrovanadium powders to deposit the (Ti,V)C carbide Fe-based composite layer on low carbon steel. It was noticed that the wear resistance improved and maximum hardness found 950 $HV_{0.2}$ due to formation of multiple carbide particles in the coating such as TiC, VC and Fe_3C. It was reported that there were no evidence of brittle fracture and debris formation of carbide particles therefore the coated layer capable to resist the plastic deformation, micro plowing and micro cutting [29]. Wang et al. (2006) improved the microhardness and wear resistance by depositing the multi-layer on the AISI 1045 steel substrate using GTAW process. It was reported that TiC phases was synthesized by in-situ process using graphite and ferrotitanium powder. It was reported that the microhardness and wear resistance achieved higher value for multi pass coating layer than single pass coating layer [30].

Conclusion

From the above discussion, it may be concluded that hard composite coating may be deposited using GTA cladding, either in-situ process or ex-situ process. This new layer of composite coating can exhibit excellent microhardness, which can protect from the various surface degradations such as wear and oxidation.

- The shielding gas affects the quality of coating and surface properties of treated layer. Coating developed under argon shielding gas achieved good quality and high hardness as compared with coating developed under nitrogen shielding gas.
- In situ synthesis provides better quality and surface properties of the coating because it eliminates the interfacial incompatibility between the matrices and reinforcements.
- The microhardness decreases with distance from top surface to the substrate due to the different-density-driven force.
- The microhardness also depends upon the formation of ceramic phases in the coating zone. It increases with increasing the ceramic phases in the coating layer.
- During in-situ synthesis, at 1025 °C exothermic reaction take place between Ti and TiO_2 therefore the Al_2O_3 and Ti phases formed, whereas TiC-TiB_2 also formed due to reaction take place between Ti and B_4C at 1100 °C.
- The melt depth and coating width depends upon the heat input of GTA cladding. At high heat input, more melting of the base metal and decreases the amount of coating particles in the coating layer, therefore increases the coating dimension and decreases the microhardness values.

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