Surface Composite Fabrication through TIG arc Process: A Review

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Abstract – Surface modification of Materials are essential in industrial applications in order to improve tribological, mechanical and corrosive properties. TIG arc surfacing is an alternative technique for modifying the surface layer and fabrication of surface composites. TIG arc surfacing method improves the surface in an efficient, user friendly and economical manner. This review article narrates the current status of the surface composite fabrication through TIG arc method.

Keywords: Surface modification, surface composite, TIG arc Process, Grain size, Hardness

1. INTRODUCTION

Surface Engineering (SE) is a multidisciplinary activity which deals with the properties of the surfaces of the solid matter. The function and serviceability of the engineering components can be improved through SE. It involves in improving the properties of the surface layer of the materials in order to minimize the degradation over the period [1]. Surface engineering can be defined as "treatment of the surface and near-surface regions of material to allow the surface to perform functions that are distinct from those functions demanded from the bulk of the material" [2]. The surface of the component has to be manufactured in a desirable way to meet the suitable service life and robust to the environment.

Surface modification process changes the properties of the surface at the certain depth level of the substrate. Physical Vapor Deposition (PVD), and Chemical Vapor Deposition (CVD) are common techniques used to deposit a thin overlay (coatings) on the substrate in the range of 1-10 µm and small interaction takes place on the substrate material [3]. In the thermal spray process a significant amount of interaction takes place on the substrate. In the carburizing or nitriding process without adding any new material on the top of the substrate, only surface modification takes place for enhancement of surface properties.

TIG arc surface method is used to modify the surface layer and for producing a thick surface composite layer; the layer thickness can range from hundreds of micrometers to several millimeters. The techniques illustrated in Fig. 1 involve the classification of surface modification processes by the depth and place of interaction and depth on the substrate.

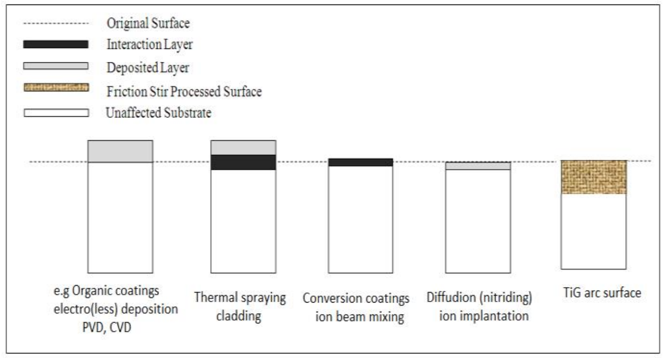

Fig. 1 Classification of surface modification processes by the depth and place of interaction and depth on the substrate [4] [Adopted and Modified]

2. SURFACE COMPOSITE FABRICATION BY TIG ARC PROCESS

The surface property of the material is very important to achieve longer life of mechanical components. To obtain the surface modification, the ceramic particles were applied on the surface of the matrix material by various techniques for enhancing the surface properties of the material. The most common methods are coating, plasma spraying, cladding, laser melt treatment, electron beam irradiation, etc. [5-6]. In these techniques, processing of surface composites is based on liquid-phase processing at high temperature. There will be an interfacial reaction between the matrix and reinforcement and the possibilities of formation of some detrimental phases are high. The ceramic particles were applied to the matrix surface and processed by TIG arc, electron beam irradiation, laser cladding techniques for enhancing the surface properties of the material.

S.H. Choo et al. (1999) [7] have deposited TiC particles on the plain carbon steel plate using high energy electron beam irradiation technique for producing the surface composite. This composite exhibited 3 to 4 times higher hardness than the base alloy due to the presence of TiC hard particles. These processes create an excellent bond between the substrate and the composite. L. Dubourg et al. (2002) [8] have modified the surface by addition of copper and iron powders on the aluminum surface by laser cladding. The hardness of Al/38Cu-11Fe(wt%) hardness was 550 $Hv_{0.2}$ whereas the hardness of the non-treated sample hardness was 20 $Hv_{0.2}$. Presence of intermetallic compounds, grain refinement and hardened surface of the aluminum matrix improve the hardness of the composite.

S. Jiguo et al. (2007) [9] have used the TIG arc source with Ni and aluminum powder preplaced on the Q235 steel plate to prepare the surface with Ni-Al intermetallics. The different current values and surfacing speed were chosen to make the beads of intermetallics. The combination of high current value of 120 A and speed of 1.5 mm/s the intergranular phase of α-Fe is formed. In the low current value of 80 A and speed of 0.9 mm/s the intergranular phase of γ-(Fe, Ni) with the large amount of Ni-Al is formed.

S. Islak et al. (2012) [10] packed with the mixture of FeW and B_4C particles in different particles ratio's (10%, 20% and 40% ratio of B_4C in FeW/B_4C mixture) in the 8mm diameter and 1.5mm deep holes in the AISI 1060 substrate. TIG arc source was used to produce the surface composite on the steel substrate. The coating thickness of 2000-2400μm was produced on the steel surface. Microhardness of the composite was 4-5 times higher than the base material. The maximum hardness value of 1095Hv was obtained at 40% ratio of B_4C powder in mixture. The base material hardness was around 225Hv. The enhancement of the hardness in the surface coating was due to the formation of carbide and boride [Fe_3(C, B) and $Fe_{23}(C, B)_6$] in the microstructure.

Similarly, S. Mridha et al. (2001) [11] mixed 53% titanium powder and 47% aluminum powder with organic binders and preplaced on the pure titanium substrate and maintained the thickness around 0.6 to 1mm on the surface. The TIG arc source operating current value of 50 to 100A and at the different speeds range of 2, 3 & 4 mm/s was selected for melting the powder to form an intermetallic coating on the substrate. The maximum melt depth of 2mm was obtained when glazed at 100A TIG arc current and speed of 2 mm/s. The energy density of the torch is the main reason for the deeper depth formation of the alloyed layer. The XRD peaks showed that the low energy density (60A) TIG arc produced TiAl structure and the high energy density (110A) TIG arc produced Ti_3Al and TiAl structure. The hardness and wear resistance of the coated surface was improved about 3-4 times than base material. In another study conducted on AISI 8620 steel, SiC/C particles diffused on the surface by TIG arc method. The hardness and wear behavior of the modified surface was significantly improved [12].

Similarly, W. Xinhong et al. (2006) [13] deposited a mixture of Fe based self-fluxing FeCrBSi powder, graphite, and ferrotitanium powder on AISI 1045 steel substrate and developed a in-situ method coating to produce TiC particles reinforced Fe-based surface composite through TIG process. From the graphite and ferrotitanium powder, the TiC particles were synthesized in the range of 3-5μm and dispersed in the matrix in a uniform manner. The hardness and wear resistance of the composite coating was improved due to the higher harness of TiC particles in the matrix.

G. Xu et al. (2006) [14] used laser and TIG cladding techniques for surface modification of stellite-6 powder on the SUS403 substrate. The hardness value of the laser clad surface, TIG clad surface and substrate were 670, 420, 200 (Hv50) respectively. The specific wear rate of the laser clad surface, TIG clad surface and substrate were $0.8x10^{-8}$, $1.8 x10^{-8}$ and $2.3x10^{-8}$ mm^2/kg respectively. The highest hardness and lowest specific wear rate was obtained for the laser clad surface. Among the various cladding process, TIG arc surfacing is a cost-effective process. It produces high thickness surface composite layer which comprises of intermetallic compounds. Metallurgical bonding nature is the specific advantage of TIG arc surfacing [10]. The Recent studies on the TIG arc process is presented in Table 1.

3. SUMMARY AND FUTURE OUTLOOK

In this review article a comprehensive review on surface modification through TIG arc method is presented. The mechanical properties such as tensile strength, hardness & flexural strength is increased due to formation of intermetallic phases. The tribological, mechanical and corrosive properties of modified composite surface is improved due to uniform mixing of reinforcement particles with matrix. TIG arc method is a straightforward and movable method in comparison with conventional heat treatment methods hence, it is convenient method for alter the selective region.

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REFERENCES

[1] A. Matthews, R.J. Hartley, P. Holiday, P.R. Stevenson, "The UK Engineering Coatings Industry in 2005," University of Hull, Hull, 1992.

[2] C.M. Cotell, J.A. Sprague, "Preface, Surface Engineering," ASM Handbook, ASM International, USA, 1994.

[3] R.F. Bunshah, "Handbook of Deposition Technologies for Films and Coatings: Science, Technology and Applications," 2nded. Noyes Publications, New York, 1994.

[4] J.P. Celis, D. Dreesa, M.Z. Huq, P.Q. Wu, M. DeBonte, "Hybrid processes—a versatile technique to match process requirements and coating needs. Surface and Coatings Technology," vol. 113, pp. 165-181, 1999.

[5] A.V. Muley, S. Aravindan, I.P. Singh, "Nano and hybrid aluminum based metal matrix composites: an overview," Manufacturing Review, vol. 15, pp. 1-13, 2015.

[6] J. Gandra, H. Krohn, R. M. Miranda, P.Vilaca, L. Quintino, J.F. dos Santos, Friction surfacing- A review, Journal of Materials Processing Technology, vol. 214 pp. 1062–1093, 2014.

[7] S.H. Choo, S. Lee, S.J. Kwon, "Effect of Flux Addition on the Microstructure and Hardness of TiC-Reinforced Ferrous Surface Composites Fabricated by High-Energy Electron Beam Irradiation," Metallurgical and Materials Transactions A, vol. 30A, pp. 3131-3141, 1999.

[8] L. Dubourg, F. Hlawk, A. Cornet, "Study of aluminium - copper–iron alloys: application for laser cladding," Surface and Coatings Technology, vol. 151–152, pp. 329-332, 2002.

[9] S. Jiguo, D. Wei, T. Wenda, Z. Di R. Jialie, "Dilution rate and microstructure of TIG arc Ni-Al powder surfacing," Frontier Mechanical Engineering, vol. 2, pp. 20-24, 2007.

[10] S. Islak, S. Buytoz, M. Karagoz, "Microstructural development on AISI 1060 steel by FeW/B_4C composite coating produced by using tungsten inert gas (TIG) process," Indian Journal of Engineering and Materials Sciences, vol. 19, pp. 253-259, 2012.

[11] S. Mridha, H.S. Ong, L.S. Poh, P. Cheang, "Intermetallic coatings produced by TIG surface melting," Journal of Materials Processing Technology, vol. 113, pp. 516-520, 2001.

[12] O.N. Celik, M. Ulutan, H. Gasan, U. Er. S. Buytoz, "Effects of graphite content on the microstructure and wear properties of an AISI8620 steel surface modified by tungsten inert gas (TIG)," Surface and Coatings Technology, vol. 206, pp. 1423-1429, 2011.

[13] W. Xinhong, Z. Zengd, S. Sili, Q. Shiyao, "Microstructure and wear properties of insitu TiC/FeCrBSi composite coating prepared by gas tungsten arc welding," Wear, vol. 260, pp. 25-29, 2006.

[14] G. Xu, M. Kutsun, Z. Liu, K. Yamada, "Comparison between diode laser and TIG cladding of Co-based alloys on the SUS403 stainless steel," Surface and Coatings Technology, vol. 201, pp.1138-1144, 2006.

[15] A. Ardeshiri, M. Heydarzadeh Sohi, A. Safaei, "Surface alloying of A2618 aluminum with silicon and iron by TIG process," Surface & Coatings Technology, vol. 310, pp. 87–92, 2017.

[16] S. Kumar, P.K. Ghosh, R. Kumar, "Surface modification of AISI4340 steel by multi-pass TIG arcing process," Journal of Materials Processing Technology, vol. 249, pp. 394–406, 2017.

[17] R. Kumar, P.K. Ghosh, S. Kumar, "Thermal and metallurgical characteristics of surface modification of AISI 8620 steel produced by TIG arcing process," Journal of Materials Processing Technology, vol. 240, pp. 420–431, 2017.

[18] Sh. Zangeneha, H.R. Lashgari, H.F. Lopezc, H.K. Farahani, "Microstructural characterization of TIG surface treating in Co-Cr-Mo-C alloy," Materials Characterization, vol. 132, pp. 223–229, 2017.

[19] A. Amirsadeghi, M. Heydarzadeh Sohi, S.F. Kashani Bozorg, "Effects of TIG Surface Melting and Chromium Surface Alloying on Microstructure Hardness and Wear Resistance of ADI," Journal of Iron and steel Research, vol.15, pp. 86-94, 2008.

[20] P.K. Ghosh, R. Kumar, "Surface Modification of Micro-Alloyed High-Strength Low-Alloy Steel by Controlled TIG Arcing Process," Metallurgical and Materials Transactions A, vol. 46A, pp. 831-842, 2015.

[21] M. Tavoosi, S. Arjmand, "In situ formation of Al/Al3 Ti composite coating on pure Ti surface by TIG surface process," Surfaces and Interfaces, vol. 8, pp. 1–7, 2017.

[22] A. Monfared, A.H. Kokabi, S. Asgari, "Microstructural studies and wear assessments of Ti/TiC surface composite coatings on commercial pure Ti produced by titanium cored wires and TIG process," Materials Chemistry and Physics, vol. 137, pp. 959-966, 2013.

[23] M.B. Karamıs, K. Yildizli, "Surface modification of nodular cast iron: A comparative study on graphite elimination," Materials Science and Engineering A, vol. 527, pp. 5225–5229, 2010.

[24] F.T. Cheng, K.H. Lo, H.C. Man, "NiTi cladding on stainless steel by TIG surfacing process Part I. Cavitation erosion behaviour," Surface and Coatings Technology, vol. 172, pp. 308–315, 2003.

[25] P.H. Lailatul, M.A. Maleque, "Surface Modification of Duplex Stainless Steel with SiC Preplacement Using TIG Torch Cladding," Procedia Engineering, vol. 184, pp. 737 – 742, 2017.

[26] N. Yuvaraj, S. Aravindan, Vipin, "Comparison studies on mechanical and wear behaviour of fabricated aluminium surface nano composites by fusion and solid-state processing," Surface & Coatings Technology, vol. 309, pp. 309-319, 2017.

Table 1. Summary of the investigations on TIG arc surfacing

Investigator Name	**Material investigated**	**Characteristic studied**	**Prominent Results**
A. Ardeshiri, et al., (2017) [15]	A2618- matrix material 30wt%Fe+70wt%Si	Microhardness and wear rate of the surface composite.	Hardness and wear resistance of the surface was improved due to formation of hard intermetallic compounds such as $Al_{13}Fe_4$, Fe5Si3, Al_8Fe_2Si, and Al_5FeSi on the surface.
S. Kumar et al., (2017) [16]	AISI 4340 steel Surface modification	Effect of TIG arc passes and arcing current on the surface properties.	Multi pass TIG arcing on the surface improves the hardness and flexural strength of the material. The optimum arcing current and arc travel speed generated the appropriate heat input in order to improve the surface properties of the material.
R. Kumar et al., (2017) [17]	AISI 8620 low alloy steel	Metallurgical characteristics of modified surface using different TIG arcing and heat input.	TIG arcing process is clean, versatile and economic process for improve the surface modification. The metallurgical transformations such as Martensite, bainite and proeutectoid ferrite took place on the HAZ and modified fusion region.
Sh. Zangeneha et al., (2017) [18]	Cast Co-28Cr-5Mo-0.3C alloy	Formation of nano scale layer on the surface and microhardness.	Formation of nano scale M23C6 carbides on the surface. The higher amount of a thermal martensite formed on the surface are responsible for improvement of the surface hardness.
A Amirsadegh et al., (2008) [19]	Austempered Ductile cast iron (ADI) & Chromium surface alloying on ADI	Microhardness and wear properties.	The formation of ledeburiitic structure on the surface enhances the hardness and wear resistance. Chromium alloying ADI surface further improved the harness and wear resistance.
P.K.Ghosh and R. Kumar, (2014) [20]	Micro-alloyed HSLA steel	Effect of autogenous Conventional (C-TIGA) and pulse current tungsten (P-TIGA) inert gas arcing process	More depth of surface modification occurred by use of P-TIGA process in compare with C-TIGA process. Multi run P-TIGA process increases the hardness with wider surface modification.

M. Tavoosi and S. Arjmand, (2017) [21]	Pure Titanium with Al 1100 grade cladding	Al/Al3Ti composite coating on Ti surface. Wear resistance and hardness of the cladded surface.	The hardness of the cladded surface was improved due to formation of Al3Ti intermetallic compound on the surface. The hardness and corrosive resistance of the composite was increasing with increase in annealing time.
A. Monfared et al., (2013) [22]	Pure titanium & TiC particles for composite coating	Hardness and wear rate of the composite surface	Uniform microstructure was formed through the depth of coatings. The hardness (1100Hv) of the composite surface was improved 7 times more than substrate. Homogeneous dispersion of hard TiC particles in the ductile matrix enhances the wear resistance of the Ti/TiC composite surface.
M.B. Karamıs and K. Yıldızlı (2010) [23]	Nodular Cat Iron (NCI)	Surface modification through elimination of graphite nodules on the surface.	The surface was modified with required depth by controlling the process parameters in order to modify the nodular graphite structure.
F.T. Cheng et al., (2003) [24]	AISI316 stainless steel & NiTi wire for cladding	Dilution rate and hardness of the cladded surface.	Thick NiTi laye with Fe and Cr was formed on the surface through strong interfacial bonding between the NiTi and steel substrate. The hardness (700Hv) of the cladded surface was higher than base Stainless-steel hardness (200Hv).
S. Mridha et al., (2001) [11]	Commercial pure Titanium(Cp-Ti)	Surface hardness	The surface hardness(2000Hv) of the surface modified surface was improved due to formation of titanium nitrides on the surface.
P.H. Lailatul and M.A. Maleque, (2017) [25]	Duplex Stainless Steel with SiC powder for coating	Effect of welding process parameters on hardness of modified surface.	The hardness of the modified surface was improved 2 to 3 times than base alloy. The dendrite microstructure was formed during melting of steel and uniform mixing of SiC particles with the steel are the main reasons for enchantment of hardness.
N.Yuvaraj et al., (2017) [26]	Al 5083 with B_4C nano particles	Hardness and wear properties.	The hardness and wear properties of the surface composite fabricated through TIG arc process was improved due to uniform dispersion of reinforcement particles in the matrix.