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An overview on the importance of surface modification by TIG and lasers incorporating carbides and their relations to wear behaviours

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ABSTRACT

Surface modification is a technique via induction of high energy input to produce a hard resilient thin layer on the surface of the weak substrate. Despite by lasers capable to produce surface modified structures, their vehement cost of manufacturing is not comparable to the TIG torch melting technique which can develop similar quality surface with less cost. To the extent of author's knowledge, the constant degradation of metal surfaces during friction are most likely to use wear test analysis in order to assess the durability of the coatings. This work takes another important step in discussing the importance of surface modifications at high energy inputs via incorporating reinforcing material by improvising micro-hardness property and finding relationship with wear behavior of the surface modified materials. Several issues on the wear behaviour of coatings mainly from the effect of surface hardness and those without coating with regard to their applications were highlighted. Periodical wear which the author’s enthusiast as a fresh niche area of wear wasn’t that much being explored; hence, explanation was extended at the end of this paper.

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1.0 INTRODUCTION

The purpose of hard layer coating is to establish a thin hard layer which is resilient enough to prevent rapid deterioration whilst minimizing downtime and service subjected either to wear, erosive or corrosive environments. Commonly, intermetallic or metal matrix composites layers formed under high energy inputs are preferred to act as surface barriers although to owe this involved in the little rise of prices but may be cheaper than manufacturing the bulk metal with equivalent properties as coatings. To take advantage from the melting processes additional metallic and ceramic particles are used to create top metallic or intermetallic layers (Md Idriss et al, 2013; Mridha et al., 2001; Kumar et al., 2019). Another effective method is by hardening layers without incorporating reinforcing material (transformation hardening) are persuasive to retain material composition to deliver the service at shorter life span period. Even though lasers melting or electron beam melting are well known for their exceptional quality of coating, indeed the processes are costly and demand specialist to operate which had opened windows of opportunity for TIG as an alternative because of their available flexibility, ease of operation, non-complexity hence, reducing the operational cost (Lifang et al., 2000; Liang and Zao, 2002; Basile et al., 2018; Musa et al., 2017). The illustration describing the melting between lasers and TIG techniques are shown in Fig.1. Lasers use irradiated light while TIG with fused arc to melt the top surface of the metal substrate either with or without incorporating the reinforcing material. The importance of formed surface layers exhibiting different compositions, phases, distribution and homogeneity than substrate through high energy input had been prudentially measured and demonstrated by adamant results of the wear subject whereby goals are to reduce the surface depletion (Sahoo et al., 2016; Gu et al, 2018; Wang et al., 1999; Wang et al., 2009; Howe, 2016; Li et al., 2011; Rasool and Stack, 2014). These are the general phenomenon that had brought a special attention and interest to develop coating layers on materials owing to their inferior of low in hardness, strength, fatigue and creep resistance.

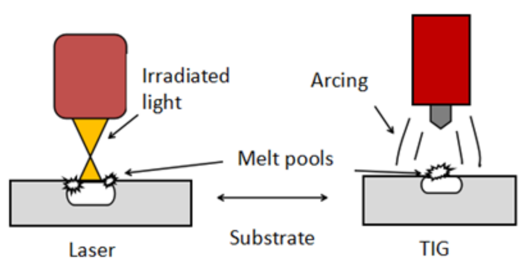

Figure 1: Illustration describing the laser melting process (left) and TIG melting process (right) on the surface of substrate.

Volatile economic factor may not always favour substitution components as new delivery for replacement may involve in many operational delays. Since incorporating the reinforcing material under the influence of TIG arc to cover the ductile and low in strength substrate promotes for a little increase of melt height with the remaining depth below the substrate surface, rather for that replacement, this melting method is not strange to rebuild, repair or to salvage defective areas such as worn surfaces, pores or interior cracks. With this technique, a sufficient melt depth of about 1 mm can be proposed for a prolong and efficient run in the continuously aggressive operated system or in a harsh environment while leaving enough substrate away to the interior to act for energy absorption sites and minimizing vibrations. Engineering ingenuity to establish the coexistence between the service from the hard layer and deliberate consideration to reduce the volume of material for an appealing and in pursuit for lightweight material may result in an establishment for reduction of energy consumption. Those above are complex argument to define and highlight the need of surface melting in many engineering disciplines rather than laboratory works that explicitly explain science at microscale level which if about optimization of melt, predicament and route for expected changes; the surface quality against processing conditions is commonly discussed. With the success of TIG works originated through extensive investigations and effort thereafter scientific explanation and publications, issues to defame surface engineering for industrial solutions namely for in automotive, mining and aerospace or petrochemical can be avoided.

2.0 EXPERIMENTAL PROCEDURE

2.1 Surface Modifications

Trial works are as important as selecting the correct and suitable processing parameters where both criteria are essential to control melting variables trailing for an optimum condition. Literatures, operator skills and experience and reports help but they are not always true for researching on new materials that requires effort and time to develop. Improvising component surfaces need a thin layer to be modified and it appears to be better to reinforce adding stronger and harder material rather than without any incorporation of material that would result the surface enduring only phase changes and not composition changes in the melt pool upon melting (Md Idriss et al., 2013; Mridha et al., 2001; Basile et al., 2018; Sahoo et al., 2016; Gu et al., 2018). Using cheap or expensive processing techniques, many reports have shown that surface modification developed hardness several times than the substrate materials (Paraye et al., 2020; Singh and Dahotre, 2004)

A work by Li, C. et al., (2019) reported that the melt pool sizes of the single layer laser work are strongly influenced by the amount of added particulates that was preplaced on the substrate. They demonstrated that the melt pool is restricted from being enlarged with more of mainly preplaced WC particulates because of high amount of heat required to melt those high melting carbide particulates than the substrate. Recent report showed, Neodymium-YAG laser melting the large amount of TiC powder on H13 tool steel produced dendritic microstructural features because of prolonged solidification time as heat being rejected to the matrix upon precipitation. When melting with less carbide content only little of small octahedral or small multifacet carbide prevailed which had precipitated near austenite low solidification temperature. As titanium and carbon become scarce in the solution due to the primary precipitation of dendrites, the secondary precipitation of carbide morphology changes. The authors agree that the cooling rate while solidification and TiC content played important role to vary carbide morphologies population and sizes (Dadoo et al., 2019). Prolonged solidification time made masses TiC in the aluminum matrix resulting higher wear resistant than traces of precipitation (Tang et al., 2014)

Using laser, excessive graphite with ilmenite, formed phases consisting carbides, iron and graphene on the 1020 steel that increases hardness (Khalili et al, 2019). The dual wire insertion into the melt pool which were the melted FeCrVc filler wire underneath the arc simultaneously with only heated FeCrVc wire near the melt pool edges hinders the heat input from melting more of the substrate causing reduction of dilution percentage astonishingly to 6%. Solidification of primary VC prolong solidification time to help diffusion process among elements. Heated wire was explained to leave residue in the melt pool while melting that promoted embryos for heterogeneous VC precipitation and grain refinement. As the temperature becomes lower associated with reduction of vanadium content, euctectic iron and VC precipitates (similar morphology as Fe-C in the pearlite structure of a mild steel). The developed microhardness was seen from 750 to 850 HV (Günther, 2020). In another work inserting Ni based and Ni based fused tungsten carbide filler creates segregatiion in the melt pool and to avoid this both filler (under arc and heated ones) had to be Ni based fused tungsten carbide for that fused tungsten carbide particles homogeneity at reduced dilution in the melt pool and increase of wear resistance (Günther et al., 2018). Hot wire techniques are capable to produce large clad geometry at minimal dilution whilst retaining fused carbide. This is great for renewing worn layers especially those that are badly damaged (Torims et al., 2017). Clad height that is high could fit ranges of worn layers dimension reducing amount of passes and built heights. Flux such as calcium fluoride helps to increase the heat intensity through disintegration of flux element and ionization which enlarges of the melt pool sizes under the influence of TIG arc. In this way, arc density increases and so with dissolution of 304 stainless steel substrate and TiC-Ni particulates. The dissolution are even more when the calculated input energy increases (Sahoo et al., 2017) which was also explained by others (Chryssolouris et al., 2005). Ceramics are one of important material used to surface cladding because of their interesting clad properties that offers combination of excellent strength and ductility with remarkable hardness (Wang et al, 2002; Ng et al., 2007; Yang et al., 2004; Rasool et al, 2015; Mridha and Baker, 2015). Another technique to increase the hardness rather than by adding high powder content or slowing scanning speed is by increasing the working distance and increasing the argon flow rate. The consequence via this method caused the energy to dissolve the WC less whilst retaining a small melt pool with high hardness (Singh et al., 2019). Cladding by diode laser with numerous injected powders on the respective rail steel produced hardness ranging from 300 HV to 1000 HV (Clare et al., 2012). Cladding stainless steel powder at 1000 mm/min, 3 RPM fed powder and energy at 3200 watt and stellite at 1200 mm/min, 4 RPM also with 3200 watts both produced sound coating (Lai et al., 2019). Densification of WC composite via high energy input was reported to reduce porosity content and refinement of microstructure that increases hardness (Gu et al, 2018). It is reported that scanned energy density using the diode laser to melt the nickel-based superalloy powder on the superalloy substrate needs to be less during remelting for subsequent layers immediately after the single cladding for sound structures (Kaierle et al., 2017). Excessive energy inputs at 840 J/mm^2 either incorporating 5 µm or 75 µm SiC particles produced crack while at 420 J/mm^2 with the same particle sizes, no crack was visible (Escalona et al., 2020). In the earlier work the solidification shrinkage during cooling caused cracking at the center of the melt pool along the TIG melting direction at high energy input with Fe-Cr-B powder on mild steel (Md Idriss et al., 2013). TiB and its eutectic structure with titanium contributed to high wear resistance though excessive of these phases presents defect of crack propagating through TiB phase (An et al., 2018).

Literatures have shown that under the influence of laser processing known capable to dissipate heat rapidly with minimal surface distortion, crack free and dilution produces sound structures to suit interest of many applications for durability and long-lasting performance. For similar process as an alternative to lasers with cheaper cost, TIG has shown to be a good substitution to obtain a comparable coating. In the previous work, the preplaced TiC particulate was melted on the surface of AISI 4340 low alloy steel under TIG torch at different processing conditions (Mridha et al., 2012a; Mridha et al., 2012b; Mridha et al., 2014; Md Idriss and Mridha 2012). Increasing the energy input up to 1296 J/mm with 0.5 mg/mm^2 TiC particulates, produced bigger melt pool that diluted the amount of TiC particle which is the reason for the decrease of hardness.

Adding TiC at 1 mg/mm^2 showed its significance to increase hardness among all sample because of the presence of densed population and good dispersion of hard particles. When using less amount of TiC powder at higher energy input which is over than 2000 J/mm, the melt pool exhibited re-precipitated TiC microstructures with little traces of partially dissolved TiC particulates. Because of the high affinity of titanium for carbon, precipitation of dispersed hard TiC that are in the form of globular, cubic or dendritic can be made by melting TiC particulates or melting mixture of titanium and carbon or by graphite/carbon on the surface of titanium or other metal (Mridha and Baker, 2015; Wang et al., 2008; Wu and Hong 2001; Wang et al., 2007). The amount of matrix that binds the TiC microstructures affect the hardenability of the melt pool. High dissolution of TiC particulates brought gradual hardness decrement from the surface of the melt pool down to the melt-matrix interphase. This is because of low density with the TiC microstructures at 4.66 g/cm^3 during melting above 1500 ^{o}C than the low alloy steel (7.015 g/cm^3) whilst making this hard carbide to segregate and float on the surface of melt upon solidification. Other factor that leads for gradual hardness decrement through re-precipitation of carbide is the location of the melt pool surface which is nearby the TIG fused arc. The temperature is sufficient to allow more time for particulates to dissolve and re-precipitated, enriching the top areas with carbide. When carbide is less, the hardness decreases which happened away down from the top surface of the melt pool realizing the functionally graded material. Similar explanation was also made by other authors that TiC are segregated on the surface of melt pool. Another problem associated with hardness reduction is the appeared porosity trapped in the melt pool from the released gas due to the burnt PVA binder via insufficient heat input (Md Idriss and Maleque, 2021; Md Idriss, 2016b). However, hardness developed are not always from the increase of energy that causes densed precipitation of TiC amount on the surface. In the latest report to precipitate TiC with graphite and Ti on AISI 8620 bearing steel by TIG, the undercooling from lowest heat input produced many dispersed embryos of populated TiC at smaller sizes than higher input melting that less populated at larger sizes. This smaller size particle track is seen much harder than the larger TiC one (Paraye et al., 2020). High Population of precipitated embryo upon undercooling was also explained by [Li, C. et al., 2019; Dadoo, et al., 2019]. Comparing to the heat treatment process, high content of Ti at 0.6% showed low hardness because of the TiC precipitation that consumed carbon than those below than 0.6% of Ti. With less precipitation of carbide with sample below than 0.6% of titanium, the solubility of carbon in the metal is high for developed high hardness (Huang et al., 2019). The reduction of undercooling reduces the embryo population and increases the precipitation of TiC size (Szymański et al., 2018). With the TiC at 60% added with Inconel825 particulate fused on the AISI 304 steel under TIG, the hardness developed reached 1000 HV near the surface (Saroj, 2017).

The work by Huang and co-authors (2019) reported that precipitation hardening is beneficial to increase the wear resistance of produced metal matrix composite by hot rolling and heat treatment. This result offers an opportunity to further investigate whether such strain developed at the interphase of TiC and steel matrix or perhaps with other kind of metal matrix composite sample. Increasing the traverse melting distance increases the preheating temperature from the experimental work which also in agreement from the mathematical modelling calculated values (Escalona et al., 2019). Under 100% nitrogen gas environment, a maximum hardness of about 2250 HV on the surface of formed metal matrix composite had been achieved from the utilization of laser that melts SiC particulates on the titanium (Mridha and Baker, 2007). Hardening by nitriding produced TiN dendritic precipitation which is more near the surface with higher hardness value than the middle and bottom of melt pool (Mridha and Baker, 1994; Mridha and Baker, 1998).

Most of the work in literatures subdued special interest to alter the surface layer because of the need to reduce its degradation and assessment presented results consisted of route for structural changes, constitutions, microstructural homogeneity and sizes and distribution of all those learnt characteristics are initially tested against microhardness. In surface melting, selected results could come from an observed area over a long track distance which with few literatures reported that the metallurgical, mechanical and chemistry changes are from the midway of tracks (Mridha et al., 2012a; Mridha et al., 2012b; Mridha et al., 2014; Md Idriss and Mridha 2012). However, others worked on surface melting found that preheating which is the rise of temperatures mainly ahead of the melt front is the reason for distinguishing the material and mechanical properties between the early and later area across a melt track (Escalona et al., 2016). When melting, the accumulated heat after a given distance through substrate conduction resulted for slow cooling rate and for that elucidate the coarse microstructural features and low hardness and so with the friction stir welding (Hilmy and Adesta, 2014). Due to the plastic deformation, the welded interphase between the softer Al 6061 and harder alumina-mullite under the friction stir welding yields hardness up to 800 HV (Safarzadeh et al., 2016). Under this fumeless and smokeless process, heat affected zone underneath the spinning pin experienced slow cooling that resulted lower hardness at about 60 HRB than the base metal of 95 HRB. In comparison, the high cooling rates immediately after melting, prompted the substrate for vice-versa structural properties that is much harder and fine microstructures than before melting stops. The different types of shielding gases used feature difference melt geometries over the same melt length and energy input under the influence of preheating (Escalona et al., 2014; Escalona et al., 2016; Escalona et al., 2017; Escalona et al., 2015; Patel et al., 2014;). Because of helium posseses thermal properties that retain and transport heat better than argon or nitrogen, the preheating temperature was the highest and deepest melt pool at the same 840 J/mm^2 TIG heat input (Escalona et al., 2017). Early stage of surface melting traavelling to 75mm developed hardness at 170 HV. After fusion of 225mm traverse distance, hardness was seen to developed at 150 HV which is lower than earlier value (Escalona et al., 2014). The influence of preheating by laser distinguished overlapped Ti-6Al-4V hardness to be mapped (Baker and Selamat, 2008). Evidence from preheating was from temperature difference of 50^{o}C between the early and later stage of SiC melted surfaces (Escalona et al., 2016). Preheating phenomenon was also explained using diode laser to melt nickel superalloy powder which were CMSX-4 and PWA 1426 each on the surface of notched CMSX-4 (Kaierle et al., 2017) Nevertheless the fundamental of forming hard layers to include those ceramic SiC exhibited hardness approximately at 1100 HV than without coating of 400 HV compromising to be as part of the work from principal investigation which is on the preheating effect (Patel et al., 2014). High overlapping percentages gave sufficient preheating temperature that transformed Soft NiTi to $NiTi_2$ phases which induces hardness at an increased of wear resistant (Prasad et al., 2020). Preheating temperature made subsequent TiC particulates content to easily dissolved upon subsequent overlapping passes which had resulted reduced of hardness values compared to the earlier stage (Mridha et al., 2014; Mridha and Baker 2015; Wang et al., 2007). NiCr powder was added with WC carbide subjected for injection under the laser beam to clad on the steel surface. Steel possesses higher melting temperature and thermal conductivity than NiCr and because of this more input energy is needed to allow this substrate to get melted before permitting the premixed low temperature NiCr with WC into the melt. Preheating the steel substrate is a way to decrease thermal conductivity of the substrate and so allowing them to melt for a pool at a reduced energy input while receiving those heated premixed particles for metal matrix composites. Preheating was also explained to reduce the thermal related stresses as to slow the cooling temperature (Amado et al., 2011)

However, high induction of heat is not preferential for stainless steel upon surface modification or welding. Sensitization results showed that stainless steel degrades due to the precipitation of carbide on welded stainless steel. The precipitation of thsese chromium carbide happen at or near the grain boundaries within the heat affected zone due to tempering and was explained for the cause of intergranular corrosion (Vashishtha et al., 2014; Urade, 2016). An approach was demonstrated by Amuda and co-authors to eliminate that sensitization phenomenon which by preheating the substrate to 300oC followed by welding at 293 J/mm with the Cr-Mn-Cu austenitic stainless steel. They explained the absence of those hard carbide precipitation at the heat affected zone was because of the carbon being locked in the austenitic matrix that made them not freely to move. (Amuda et al., 2018). In another work without pre-weld (preheated) the samples, they showed below than 200 J/mm produced ditched free structure along the grain's boundaries exemplifying no carbon diffusion to produce chromium carbide. At low energy input, solidification rate is high leading to carbon not migrating whilst remained in the solid (Amuda et al., 2017). Small size grain is more affected by sensitization than the large grains as the chromium had to travel far reaching the grain boundaries (Taiwade et al., 2013) Within the melt pool, formation of metastable phase of chromium carbide (M7C3) with austenitic and eutectic phases (ferrite, cementite) and other traces of alloying element succeeded via TIG melting of Fe-Cr-C powder on AISI 4140 steel. Adding NbC powder with that of stainless-steel powder gave visible NdC phases whilst extending solidification range compared to only the stainless steel and substrate (Tosun et al., 2021)

Neither of these works were found to underpin the influence of the rise of temperature within the substrate on the surface of pre-placed TiC particulates by TIG nor establish a TiC composite under different type of shielding gases. Opting surface hardening in the favour not to use heating such as with TIG or lasers, water jetting process is an alternative as it shares the same common like the traverse speed, working distance, energy input or nozzle inclination angle. With water jetting processes, either using water, emulsification of water and oil, only oil or abrasive liquid impinged on the metal surface, showed hardness development up to depths due to the surface being plastically compressed (Azhari et al., 2016). Infact, their work showed that high pressure per unit area yield depth of produced channel and surface roughness (Husin et al., 2019; Azhari et al., 2014). Deformed and slip band are evidences of increased hardness on the surface (Azhari et al., 2012) Cold work of water jetting and hot work through fusion using arc and beaming methods are capable to develop surface hardness at depths and so with burnishing of aluminum and steel using conventional ball and conventional ball with ultrasonic assisted methods at different passes (Amini, 2017).

Surface modifications had been proven by evidence that they improved the operating performance of a system in the field of engineering application. As for remanufacturing which is to rebuilt continuous wave diode laser was used to build clad layers of the worn compression mould edges through injection of Ni/Cr powder that was used in the automotive industry (Pascu et al., 2019). Thick clad layer was produced for advance nuclear application composing V, Cr and Ti via selective laser melting (Jialin, 2017). An attempt was made to produce in house facilities to clad damaged crankshaft pin bearings that were used in marine engines. They benchmark Škoda/ČKD ‟6-27 5A2L diesel engine shaft for their initial work (Torims et al., 2017). Intergrating

CNC milling, laser cladding, pre and post inspection produced adaptive technology to manufacture and re-manufacture defective or worn parts. This technology successfully demonstrated a sound layer from the blade tip defect re-manufacturing in just a single work (Jones et al., 2012). With the technological advancement, surface modification that had made ways for fabricating the 2D layers had been explored and exploited for building 3D components for prototypes known as additive manufacturing (Jialin, 2017; Kaierle et al., 2017; Vasque et al., 2012). To produce and tailor quality clad layer, experiments involved many manufacturing hours from the tabulated processing conditions and needs a personal that has vast experience to operate in laser processing. To reduce and avoid such conditions, additional devices to prompt visual, temperature, spectrum or acoustic signals are attached to the laser machine serving the purpose of in situ monitoring. This controlling system received feedback from the signals while clads are in production which would automatically alter the processing conditions so that the solidified track is according to the specification. If the clad heights are more or less, the powder feeder would decrease or increase the injection rate to return the clad height to the nominal distance (Liu et al., 2017) Steel has many times coefficient of thermal expansion than Invar. Overlapping Invar aganst steel showed higher coefficient of thermal expansion than Invar (Arbogast et al., 2020). Cracks and notch on the nickel-based superalloy substrate added with superalloy particles, were successfully remedy using diode laser through scanning strategies (Kaierle et al., 2017). Scanning strategy saved up to 29% of input energy when adding the external Ni based fused tungsten carbide hot wire associated with with the same filler wire underneath a single scan gas metal arc compared to only inserting with one wire (Günther et al., 2018)

New technologies had been developed to produce quality coating by manipulating the use of lasers. By adapting that melting technique instead of increasing hardness, manufacturing goods or components are able to be produce in a way that time, cost and effort reduced. This had been exemplified by additive manufacturing. In a latest work, a critical review on binder jetting, laser powder bed and laser powder fed of additive manufacturing using metallic or intermetallic particulates were made to fabricate samples and cladding weak substrates. Results showed that the physical and mechanical properties were improved compared to those conventional alloy (Fayazfar et al., 2018). Global players such as TWI-Global and Alloy Carbide Company are on the move to produce quality coatings and components via additive manufacturing (twi, alloycarbide).

2.2 Relationship Between Wear and Hardness

During surface friction, wear is affected by hardness and several processing conditions such as sliding speed, load, distance, sample geometry, temperatures, presence of particles, environmental and testing methods and it is one of the ways that is known and widely used to measure the durability of coatings. Wear is material loss that occurs when several of these processing conditions are synergized on the surface because of the generated dynamic force. One important character that harnesses wear is the material hardness. Hardness can be defined as the ability of the material to resist deformation. The effect of wear losses in relation to the hardenability in wear is described through Archard's eqn. in 1 that derives the volume loss (V) equals to coefficient of friction (k), load (L), speed (S) and material hardness (H). Although at certain extent this equation may be baseless because of the wear mode such as very mild, mild or severe and wear mechanism (abrasive, adhesive or oxidative) that changes due to the wear transition resulting inconsistency of volume loss throughout any test, eqn 1., however provides a fundamental understanding to suggest and select a relevant type of material to be used for an application. One should comprehend that the sensitivitiy of contact surface during friction dictates the coefficient of friction and any fluctuation of this behaviour would result in volume of wear loss to change. So, with the equation, higher load gives greater volume losses than the low load. However, this general presumption is overestimated when specific wear rate is considered to value the amount of losses. A work showed at 1N gave higher specific wear rate than at 5N though the total volume loss at 5N was higher than at 1N making calculating the specific wear rate is as importance as determining the volume losses (Merwe et al., 2013)

$$V = \frac{kLS}{H} \tag{1}$$

For the reduction of wear, the surface is rather hardened than the bulk of the entire component to preserve the feasibility of processing and engineering quality when these components are subjected to service and most importantly to reduce the cost. Many research have shown that hardening via high energy input upon incorporating reinforcement gave exceptional surfaces to highly resist wear whilst prolonging the shelf life of those layer during operation. With the TiC-Inconel 825 composite made by TIG processing, the TiC microstructures act as barrier against the matrix plowing under the dry sliding wear test. More of this carbide reduces such flaw and so increases the microhardness of the developed layers (Saroj, 2017). Dendritic growth appeared on the modified surface after melting the Inconel 825 alloy powder on the 304 stainless steel seeing hardness developed up to 350 HV. High amount of preplaced powder at 0.7 mm thickness layers are less diluted against the substrate whilst retainining more of alloying elements in the clad resulting high wear resistant. At 0.5 mm thickness layer (less Inconel) alloy are diluted with the substrate and when this happen, the samples are poor to resist wear (Saroj et al., 2020). TaC has the property of grain growth inhibitor and adding this hard ceramic at 0.09 wt% and 0.01 wt% of Nbc exhibited spread of carbide particle at smaller grain sizes in the WC-Co 5.9 wt% composite. With higher content of TaC at 3.6 wt% associated with TiC, that TaC becomes not effective to inhibit grain growth and so hardness reduces to about 1600HV than the former at about 1900 HV (Merwe et al., 2013). The metal matrix composite layer consisting of TiC precipitates within strengthened solid solution of Fe matrix exhibited wear resistance at 11 times under about 60 kg of load at 6.67 rev/sec of sliding speed than steel (Wang et al., 1999). Because of the multicarbide formed by mainly by Ti and V, the wear scars are visible with smoothness with the absence of adherence than TiC coating and the uncoated surface (Wang et al., 2009). TIG produced increases hardness up to 400 HV with increase of energy input using powder below than 50 μm SiC size (Reddy et al., 2014) which was also similar to another report (Lailatul, 2018).

During wear, particulates or third body particles generated from the surface depletion are chemical composition from the debris of the worn pin and disk. As these powders accumulate and crushed to smaller pieces, the porosity and oxidation alters the chemical composition and surface appeal whilst increases the particle hardenability. Particles that possess sharp angular and hard are potential to cause excessive amount of wear (Hutchings, 1992). Soft particles are harmless for such deterioration. Classification of track failures can be identified by the sizes and types of the third body abrasive particles (Alam et al., 2002). The large debris are evidence of wear severance from the untreated sample while the hardened layer showed fine ones (Mridha et al., 2001). When the amount of this TiC exceeded optimum content, wear resistance of the composite is reduced (Rao et al., 2016). Scrathces that are available due to abrasion across the matrix necessisating severance are not significant to deteriorate because of the TiC are well disperse and bonded to the matrix (Sahu et al., 2020)

Others have reported that the removal of WC particulates was the cause for the iron debris to be crushed to smaller pieces and this third body particles rather than allowing excessive failures, they cushioned the counterpart to glide among asperities (Yan et al., 2018). This was differed in another work showing Vanadium carbide-Fe debris resulted severance on the wear track (Li, X. et al., 2019). In their work, the well dispersion of carbide at 565 HV (specimen 2) improved the wear resistance significantly at 5.4 x 10^5 μm^3 while the lowest and the highest hardness at 521 HV (specimen 1) and 603 HV (specimen 3) are more severe at 11.5 x10^5 μm^3 and 8.6 x10^5 μm^3. Specimen of the lowest hardness (521 HV, specimen 1) failed through deformation while with the highest hardness (603 HV, specimen 3) experiences spalling or abrasive wear. Intermediate hardness (565 HV, specimen 2) with well dispersed carbide protects the matrix against being deformed and extreme abrasion and so giving the lowest volume loss.

Rough surface should be eliminated to preserve less fluctuation of friction (Kumar et al., 2019). In another report, rippling marks on the melted surface was postulated to influence wear (Escalona et al., 2020) and research on their wavy formation was also reported by other works (Md Idriss et al., 2012 and Md Idriss et al., 2013). It is viewed that rippling marks with their peaks making contact with the counterpart shall endure extreme wear which these corrugated surfaces are normally removed by grinding or by machining to reduce that roughness. The rough surface effect was explained by contact surfaces between the rider and the ridden during mating that coincide the low followed by high wear resistance resulted demarcation trend of coefficient of friction with decline and sudden rise of behaviour trend (Kumar et al., 2019; Zine et al., 2018). Upon wear different sizes of grooves alleys are clear indication that the mechanisms to govern such flaw arises from micro-cutting (Li et al., 2011). The pits were the source of tribo-powders entrapment and comminution under subsequent alumina passes which is suffice enough to provide the third body abrasive that accelerated damages on the worn track (Magnus et al., 2018).

At the speed of 3 cm/sec under 2 N, the uncoated 303 stainless steel showed adhesive wear to be distributed across the scar while after incorporating TiC to harden, the surface failures had little deformation. With higher speed and load at 15 cm/sec and 8 N respectively, both surface failures are severe for preference of more deformation with uncoated while the coating are with 'pull-out' of TiC microstructures (Rasool and Stack, 2014). In the work, the 303 stainless steel hardness value without coating is 172 HV while with TIC coating is 347 HV. The level of wear severance determined from the wear rate was classified in their work as shown in Table1. The result at the speed of 3 cm/sec under 2 N gave wear rate at 93 x 10^{-7} g m^{-1} while at 7cm/sec of 8 N, the coated sample experience 22 x 10^{-7} g m^{-1}. The wear mode of both samples without and with coatings are classified as medium wear and mild wear respectively according to Table 1.

Table 1: Classification of wear mode (Rasool and Stack 2014).

Wear mode	**Classification (g m^{-1})**
Very mild wear	X < 20x10^{-7}
Mild wear	20x10^{-7} ≤ X≤ 91 x 10^{-7}
Medium wear	91 x 10^{-7} < X≤ 274 x10^{-7}
Severe wear	X > 274 x10^{-7}

Table 2: The relation between coating hardness and durability against wear.

Author	Process and Material. Technique/reinforcement/substrate)	Microhardness	Wear, durability of coating
Mridha, 2012a	TIG/TiC/AISI 4340	To 1100 HV	N/A
Rasool and Stack, 2014	TIG/TiC/303SS	347 HV	44x than 303SS
Wang, 2009	TIG/Graphite+FeTi+FeV/AISI 1020	To 900 HV	6x than AISI 1020
Li, 2011	Laser/Ti+B_4C+Al/Ti6Al4V	N/A	9.5x than Ti6Al4V
Li, C. 2019	Laser/WC+AlSiTiNi/304 SS	To 1000 HV	5x than 304 SS
Pascu, 2019	Laser/Ni+Cr powder/steel	To 600 HV	N/A
Ng, 2007	Laser/Mo+Ni/Copper	To 650 HV	15.5 x than copper
Yang, 2004	Laser/Ni alloy+Ti+C/	To 950V	N/A
Szymański, 2018)	Casting/Ti+C powder/Steel liquid	To 900 HV	6.3x than steel
Zhao, 2019	Casting/TaC/gray cast iron (GCI)	To 20 GPa	16x than GCI
Li, J. 2019	SLM/316Lss+TiC/316Lss	To 343 HV	1.2x than 316Lss
Sekhar, 2020	TIG/TiC/AISI 1020	To 650 HV	N/A
Lailatul, 2018	TIG/SiC/ Duplex 2205 (DSS)	To 1000 HV	2.7 x than DSS
Yan, 2018	SLM* vs CSAM*/WC+Maraging powder	To 450 HV	12.3x than CSAM
Chauhan, 2017	Sintering followed induction hardening/Fe-Cr-Mo-graphite	233 HV (S), 600 HV (IH)	N/A
Amuda, 2020	TIG then heat treatment/Austenitic SS	To 600 HBN	N/A
Kilic, 2020	Thermal diffusion/TiC/AISI 4140	To 1300 HV	N/A
Ariff, 2018	HIP*, HP*+HMW*/88Si_3N_4	1124, 1438HV	N/A
Sardar, 2020	Stir casting/ Alumina+aluminum	To 135 HV	4x than as cast

HIP*=Hot isostatic press,HP*= Hot press, HMW*= Hybrid microwave, SLM*= Selective laser melting, CSAM = Cold spray additive manufacturing

Using the TIG process, melting the WC-10Co-4Cr was coducted on the AISI 304 steel. The high decarburization of WC at high heat input produces harmful W_2C phase that gave reduction of bonding to the CoCr. This unfavourable condition made those W_2C to easily pulled out from the wear track track that increases the weight losses at different sliding speed (Singh et al., 2020a). The similar pulled out or detached carbide phenomenon took place on the worn surface, reduces the load bearing support of the TiC metal matrix composite and limited the amount of stress to be transferred from the matrix to the particulates whilst exposing this soft phase for extreme wear. The reduction of weight loss at higher sliding speed was due to the lessening of intimate contact between the counterpart and the composite happened at very short time and oxidation that helps to provide solid lubrication properties both synergized to reduce friction (León-Patiño et al., 2019). Comparing the TiC added with stainless steel substrate and those without particles addition, the mechanically mixed layer work hardened and formed thick layer. Having no carbides, wear becomes worst with adhered transfer material to easily loose with only thin mechanically mixed layer that had formed (Li, J. et al., 2019). Generally, when the ridden disk or pin are subjected to extreme surface friction under high load speed, the mating surface experiences hardening due to the continuous densification. The produced hardenability gradually depletes as it moves away to the inner side or material core. This suggest that the gradient hardness profile from the surface has a definite effect to increase the wear rate as it moves for the core which is at the softer side. It has been reported that the generation of compressive stress between 3 m/s to 6.1 m/s of sliding speed induced strain hardening underneath the wear surface that increases the microhardness with Al 2219/15SiCp and Al 2219/15SiCp3Gr (Basavarajappa et al., 2007). While with the functionally graded coating, the gradual hardness and density decrement of SiC-Al/Ni metal matrix composite are associated with increase of wear rates from the surface of the sample to the bottom (León-Patiño et al., 2013) and so could be with the TiC coated on steel via TIG (Mridha et al., 2012a; Mridha et al., 2012b; Mridha et al., 2014).

Wear testing under the air environment using Zirconia against Al-Si surface produced oxides that extended the mutual surface damages causing the rate of wear two times higher than the inert argon environment exhibiting deformed wear (Baker et al., 2010). The recent work with TiC on AISI 4340 low allows steel; 700 HV, sustain coefficient of friction approximately 0.4 due to the third body abrasive and impingement from protruded carbide while comparing to the uncoated sample at 300 HV, the friction gradually rises from 0.28 to 0.34 as a result from adhesive wear both tested for 4 hours at 500 meters of travelling distance (Md Idriss et al., 2016a). The small size of melt pool under 80 ampere incorporating TiC particles on aluminum produced a dense hard surface that increases wear resistance than the diluted melt under 100 amp (Toozandehjani et al, 2020). Cut pin from the melted tracks of fused TiC on the surface of AISI 1020 mild steel sample were subjected to the dry sliding wear test. More carbide fused at 120 amp resulted the best wear resistance compared those fused at 110 and 100 amp due to better particles matrix bonding from sufficient melting (Sekhar et al., 2020). Not only wear at room temperatures, incorporating carbide particulates were seen to improve wear resistance close to 1000^{o}C. One work showed that the addition of Fe-28Al-5Cr with TiC particulates up to 50 wt% showed improved of wear resistance between 28-35 times than the substrate alone under the dry sliding wear test up to 800^{o}C testing temperature. At elevated temperatures, the formation of TiO and FeO helped to give lubrication properties that had showed reduction of coefficient of friction than those near to the room temperature (Zhang, 2013). TaC composite coating slided against steel endures abrasive wear at room temperature and at 600^{o}C the wear mechanism changes to abrasive and adhesive with oxidative wear seeing weight gained rather than losses than the room temperature, 200^{o}C and 800^{o}C (Zhao et al., 2019). TiC coated layer resisted the formation of oxide layer tested at 600^{o}C under the dry sliding wear than AISI 4340 low alloy steel (Md Idriss et al., 2017)

It can also be seen that wear were tremendous when higher load is applied compared to low load. Wear is strongly related to the hardness of the coated samples. In this literature review the influence of wear against the hardness is summarized in Table 2 which was observed from several research work. It can be concluded that the wear resistant increases with increased of surface hardness. Here, it is the matter which hardness that suits for an application because very high hardness may initiate crack upon sudden impact. This is why ductility or toughness either in the matrix or substrate to increase the coating durability and toughness become a topic of interest - to reduce the possibility of crack.

2.3 The Intermittent Wear

Wear by introducing interference repetitively to disrupt the consistency of friction surfaces are called intermittent wear which in our perspective can be classified to two categories. The first order of intermittent wear, is classified as continuous dynamic motion of the ridden sliding on the surface of the static rider or vice versa that is either one being the static which is fixed to the machine. The second order is the extension phenomenon from the first order that is by interfering wear progresses by stopping the test for a moment before they are being put back again to sliding motion. Not only stopping, interference could also be used by pulsing the parameters of loads, speeds, lubrications, abrasive particles, gasses, heating or cooling to break the consistency of coefficient of friction by oscillating the wear behavior on the contact surface.

An example of intermittent wear is the revolving sprocket against the chain functioning as driving train to transmit load for rotating the wheels such as that in the motorbikes or bicycles. Sprockets made from blanking the low carbon steel showed gradual increase of hardness at the sheared surface which was across the component thickness (7 mm thick sprocket). Medium carbon steel sprocket followed by heat treatment resulting absence of deformed grain had the almost equivalent hardness. Both sprockets, the blanked (low carbon) and outsourced (medium carbon) experienced work hardening up to 10% from microhardness results after 40 hours testing (Thipprakmas, 2011).

Intermittent wear had been extensively used to test the braking system having various kind of pad ingredient fabricated against the sliding disk brake rotor of automotive vehicles. Increase of temperature during the braking especially at high pressure decreases the braking efficiency because of the high heat generation (brake fading). This is usually followed by recovery when braking pressure becomes less and temperature start to decrease. Excessive amount of natural fiber was also described for the reduction of braking effeciency. (Adebisi et al., 2011; Kasolang et al., 2011; Maleque et al., 2012; Maleque and Atiqah 2012; Wan Nik et al., 2012; Singh et al., 2020b,).

Either the mild or severe the first order that runs on the developed contact surface consistency are expected to wear less than the second order needing sequence of passes to build contact conformity many times and endure wear transition that could end with high wear rates. From these assumptions, wear is expected to be looked further into and perhaps new ground could be presented from the arrival of much complicated behaviors when at least two of among these parameters combined in a test (for example pulsing load and speed). Not all interference is deteriorative. Lubrication using oil or water may help to ease wear by creating a thin protective film that enhances the contacts to glide between the surfaces at minimal wear. Without lubrication the sharp and hard entrained particles penetrate the flat surface which accelerates the surface damages (Hutchings, 1992) while sudden load increment or speed may induce, deformation, abrasiveness, oxidation or fatigue cracking which all are thought to give sharp rise of wear. Breaking up the contact regularity through certain intermittent medium destabilizes friction of coefficient thus affecting the wear rate.

3.0 CONCLUSIONS

In order to increase the efficiency of a mechanism subjected to friction, wear is the key factor that needs to be reduced. One of the methods to triumph this objective is to have a hard, resilient, and durable coatings (with higher hardness) for a potentiality to garner less weight loss, surface failures and possibility for low coefficient of friction which can be done through the cheap, flexible and maneuverable TIG technique. Reinforcement such as carbide surfacing should have the main intention to prosper wear reduction and increase the system performance and not to ultimately bear the high load. If it is load then, lubrication should be adapted. Different kind of gases such as nitrogen, argon or helium and manipulating working distances or flow rates are seen to be sufficient due to easy processing for producing hard surfaces at very minimal cost. Versatile layers are able to be tailored using surface modifications at different composition, producing tolerable fit namely for industrial applications rather than having the whole body with equal property as the modified surface. Induction hardening process seems to be a reasonable method to produced hard surface via incorporation of alloying particle or selective gasses without producing undulated of rippling marks like melting by the TIG which subsequently requires extensive grinding to produce smooth surfaces. Instead of only covering spans of soft areas to produce hardness, taking several processing advantages, it is not peculiar to produce the 3-D structure using TIG technique bringing this cheap process one step closer to the lasers. This work is hoped to bridge the gaps between the importance of having hard structure under selective processing technique incorporating carbides with regard to their hardness and wear behaviours (especially intermittent wear) whilst delineating advantages useful for automotive, aerospace, naval, or oil and gas application.

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