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# Improved system for Butterfly Valve

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***Abstract***–A cost-effective procedure to surface alloy WCB steel butterfly valve sand castings using mold coatings incorporating metal and ferroalloy powders has been described.The tooling, mold design, and casting conditions similar top lain WCB castings were successfully used to produce sound surface alloyed butterfly castings under industrialconditions. The dynamic behaviour control of a butterfly valve is important because , when one of the valve disc natural frequency is close to the frequency of vortex shedding, which appears when the valve is fully open or partially closed, resonance may appear and vibration with significant amplitudes is generated.The surface alloying was achieved by addingpowders of Ni, Cr, Fe–Si, Fe–Mn, and Mo to the slurrycontaining a binder coated on the mold surface. The sur-face alloyed coatings on the surface of WCB steel butterfly valve castings were enriched in Ni, Cr, Mo, and Mn up to 6.4, 23.2, 3.3, and 1.1%, respectively. The depths of coatings were as high as 420 lm. After normalizing and tempering heat treatment, the surface alloyed layer exhibitedan increase in corrosion resistance as compared to base metal WCB steel.

***Keywords***– surface alloying, corrosion, austenite phase, heat treatment, butterfly valve, nickel, chromium, manganese, silicon, molybdenum

## I. INTRODUCTION

Many metallic components used in applications involvingexposure to the corrosive aqueous and atmospheric conditions suffer from the degradation of the surface. These problems are especially widespread for castings that are utilized in the water supply industry, including pumps, butterfly valves, valve seats, faucets, and flanges. To prevent corrosion on the surface of these components, water industries rely on coating sousing casting stainless steel components on account of their corrosion-resistant properties.[1]Since corrosion is a surface phenomenon, mainly the surface of components needs to be corrosion resistant as compared to the core of the material, and therefore, surface alloying techniques can be applied to change the composition of surface in order to improve corrosion resistance. Various surface alloying techniques have been reported inthe literature. Jiang et al. performed surface alloying of multi-element Ni–Cr–Mo–Cu surface alloyed layer on low-carbon steel and AISI 304 stainless steel materials using a double glow plasma process. [2]It was observed that the relative content of $Cr_2O_3$ in the passive film of the alloying layer formed on the 304 stainless steel is 3.75% more than that in the passive film of the alloying layer formed on the low-carbon steel, and this corrosion-resistant film was infavor of the corrosion resistance. Majumdar et al. investigated the effect of(WC-Ni-NiCr) used as a corrosion-resistant alloying powder that was applied on the surface ofAISI 304 stainless steel by laser surface alloying process.[3]The microhardness of the alloyed zone was significantly improved to a maximum value of 1350 VHN as comparedto 220 VHN of as-received c stainless steel. Krishnakumarand Srinivasan used gas tungsten arc for surface alloying stainless steel with titanium and tungsten,[4]and Fals et. al. used laser surface alloying on flame prayed NbC coatings on a stainless steel substrate.[5]Jeyaprakash et al used lasercladding to add nickel and cobalt coatings on stainless steel substrates. [6]Amirsadeghi and Sohi studied the surface melting of a us tempered ductile iron using the TIG processwith molybdenum and chromium as alloying elements that leads to the formation of a hardened alloyed layer. [7]Surface enrichment by ball milling is an alternate technique used to improve the pitting corrosion resistance of stainlesssteel. 316L stainless steel is enriched with approximately18% Cr, which helps to prevent surface corrosion, but theaddition of Mo can help to prevent pitting corrosion aswell.[8] Electric discharge surface alloying has been con-ducted with a chromium anode where in an electric arcproduced by the anode lead to rapid melting and solidification of chromium on the surface of low-carbon steel.[9]The surface of 304 as a substrate has been laser clad with 316L stainless steel and WC powders using a 700 W laserto form a surface with improved hardness.[10] Cao, et.al., used a mixture of V, Cr, Ti, and Mo which was applied tothe surface of the substrate which was alloyed using a high temperature plasma arc with a maximum energy density of $10^6$ $W/cm^2$. [11]All of these processes showed major improvements in the properties of the substrate, but they are mostly expensive methods and cannot be applied on large components as needed in water distribution system. Surface alloying by casting is a good solution to impart high local wear and corrosion resistance to cheaper and common industrial materials. The idea of surface alloying of mild steel was first patented in 1969 by the International Nickel Company. [12]The process was developed to surfacealloy gray iron, alloy cast iron, and alloy ductile iron with nickel and chromium-containing metallic powders, and other nickel alloy powders. Some of the main characteristics of surface alloying during casting

 

include:
(1) the surface properties of materials and parts can be tailored to specific requirements (resistanceagainst corrosion, wear, oxidation);
(2) The alloyed layer ismetallurgically bonded to the base metal; and
(3) Surface finish can be controlled and machining allowance can beprovided. Ni and Cr are the frequently used alloying elements for improving the performance of various iron alloys such as the wear resistance, corrosion resistance, and thermal resistance.

Ni can dramatically improve the chemical stability of the iron alloys so as to increase their corrosion resistance. Cr leads to the formation of an oxide layer, which is highly protective against corrosion reaction. In the present study, we developed targeted multi-elementNi, Cr, Fe–Mn, Fe–Si, and Mo enriched surface alloyedlayer coatings on the WCB steel butterfly valve on industrial scale using gravity sand casting process for improving its hardness and corrosion resistance properties. These elements for enrichment were picked since they are present in super duplex stainless steels, which have very high corrosion resistance. A butterfly valve is a quarter-turn rotational motion valve, which is used to stop, regulate, and start the flow. This valve can be used in many differentfluid services such as cooling water, air, gases, and fire protection; slurry and similar services; vacuum service; and high-pressure and high-temperature water and steam ser-vices. Characterization of the microstructures and phases inthe surface alloyed layer has been carried out to understand the effect of process parameters. Micro hardness and corrosion resistance have been measured.

## II. EXPERIMENTAL PROCEDURE CASTING PROCEDURE

The industrial butterfly valves casting molds (Figure 1) were obtained from an industrial foundry (hereby referred to as the industry) to demonstrate surface alloying. Fig-ure1a, c shows pictures of the actual molds. The moldswere made from 80-grain fineness silica sand. A phenol cure than organic binder system (binder level*1.2%) was used to ensure good gas permeability and surface finish during casting. The catalyst used was set to allow for an8–10-minute work-strip time. The sand and binder / catalyst chemicals were mixed in an Omega Tinker industry mixerand then dumped onto the pattern. The sand was manually smoothed, as well as with a strike-off bar, and allowed toset for 10 minutes. After the curing was complete, and them old halves were extracted from the pattern by flipping inversion of the pattern using a manipulator crane. The mold cavities were coated with are factory wash (REFCOTECREFCOHOL1010) to avoid any reaction between the molten metal and the sand. After applying binder and surface alloying elements on mold and allowing the slurry to dry and harden (Figure 1b, d), the molds were closed, and a zircon filter was placed in the down spruce of the mold.

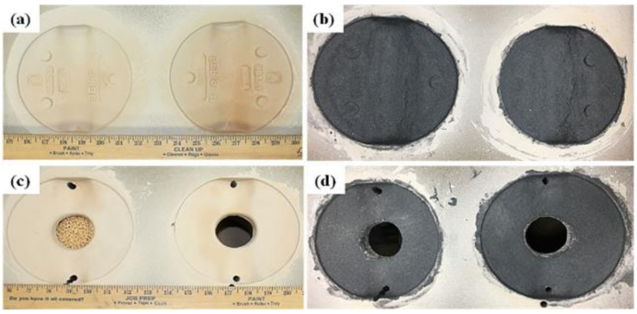


Figure1.Butterflyvalvemoldsforindustrialcasting.(a,c):Bareand cleaned surface coated with zircon; (b, d): multi-element powder-coated mold surface using sodiumpolyacrylate.

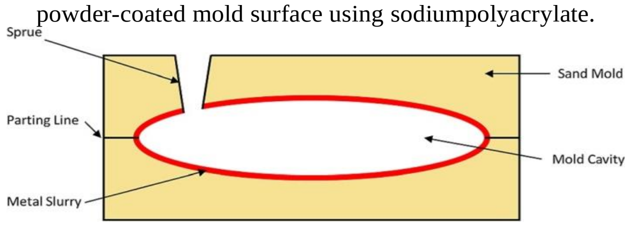


Figure2.Schematicdiagramofthesandmoldwiththealloying powder slurry applied on the inner surface of the mold cavity. The alloying slurry is a combination of the alloying powders and the binder medium.

Then, three samples were made using two different techniques. The first two samples were prepared by adding theNi and Cr powders onto a wet refractory wash coating, and the third sample was made using as blurry containing Ni,Cr,Fe–Mn, Fe–Si, and Mo mixed with sodium polyacrylate (NaPA) binder. Figure 2 shows a schematic representation of the sand mold before the WCB steel melt is poured. Once the mold surfaces were coated, they were sealed using Sonic STIK®—core and mold adhesive. The moldswere then transported back to the industrial foundry for casting. Once the casting shad was poured, they were shaken out and shot blasted with steels hots, and risers and gating were cut off at the industry and were then transported back to the laboratory for analysis.

Figure 3 shows a commercially available butterfly valve, and the surface alloyed butterfly valve prototypes cast at the industrial foundry in the present study. The objective was to quantify the levels of enrichment that could be achieved in an industrial setting for casting a component which requires high quantities of alloying elements on thesurface for wear and corrosion resistance. The chemical composition of the WCB base alloy is presented inTable1. Table 2 presents the composition of the alloying elements used for the surface alloying of the industrially cast butterfly valves.


Figure3.(a) A commercially available butterfly valve, (b)surfacealloyedbutterflyvalveprototypescastattheindustrialfo undryandUWM

 

## III. LINEAR POLARIZATION TEST

Linear polarization testing was carried out to measure thecorrosion current of the surface of the sample. The material is polarized during this test on the order of ?/- 25mVonanopen-circuit potential, and the potential is measured when no net current is flowing. As the potential of theworking electrode is changed, a current will be induced to flow between the working and counter electrodes, and the sample's resistance to polarization is found by taking the slope of the potential vs. current curve. The advantage of this test is that it is non destructive, unlike the potentio dynamic polarization test, and it does not change the chemistry of the surface .The samples were conditioned in an ASTM G61 3.56% salt water solution for one hour and then underwent a linear polarization test for 10 minutes. A potentiostat, SP-200BioLogic, was used to run the test. The electrolyte used forthe corrosion test was 3.5% NaCl solution. The surfacealloyed samples and graphite rod were used as the working electrodes and counter electrodes, respectively. For the reference electrode, Ag / AgCl electrode was used.

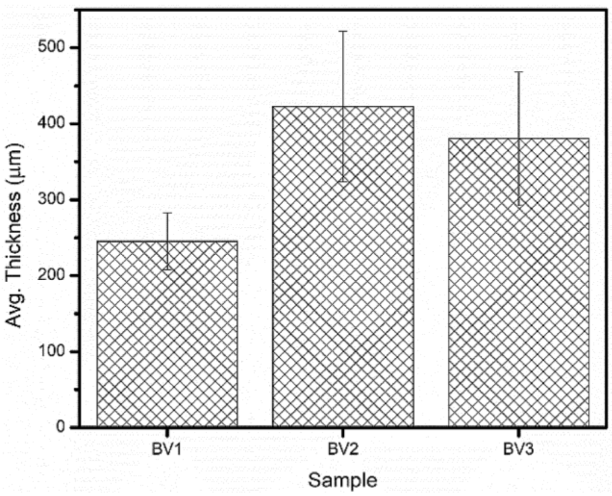


Figure4. Average thickness of the surface alloyed layer in three castings of surface alloyed butterfly valves.

Optical micrographs of the cross section of surface alloyed as cast samples are shown in Figure4. A relatively uniform and continuous surface alloyed layer was observed in allsamples. Occasional microporosity is observed in the sur-face alloyed layer. The average thickness of the surface alloyed layer is given in Figure 5. Electro-etching of the surface alloyed layer was performed using an etchant made with 15% HCl and 85% ethanol andpassing a 2 Amp current using an electrode placed on thesurface alloyed layer. The base metal (Figure 6a) shows after rite and pearl its micro structure, which is typical of WCB steel. Figure 6 b–d demonstrates the cross-sectional macro-morphology of the surface alloyed layer, indicating a surface alloyed layer free of cracks or porosity. The interface layer between the base metal and the surface alloyed layer does not show the presence of cracks.

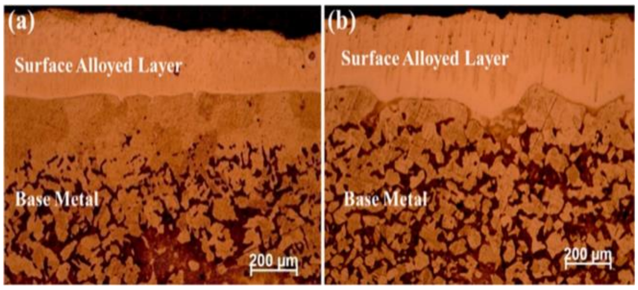


Figure4.Opticalimagesoftheas-cast(a)BV1and(b)BV2.

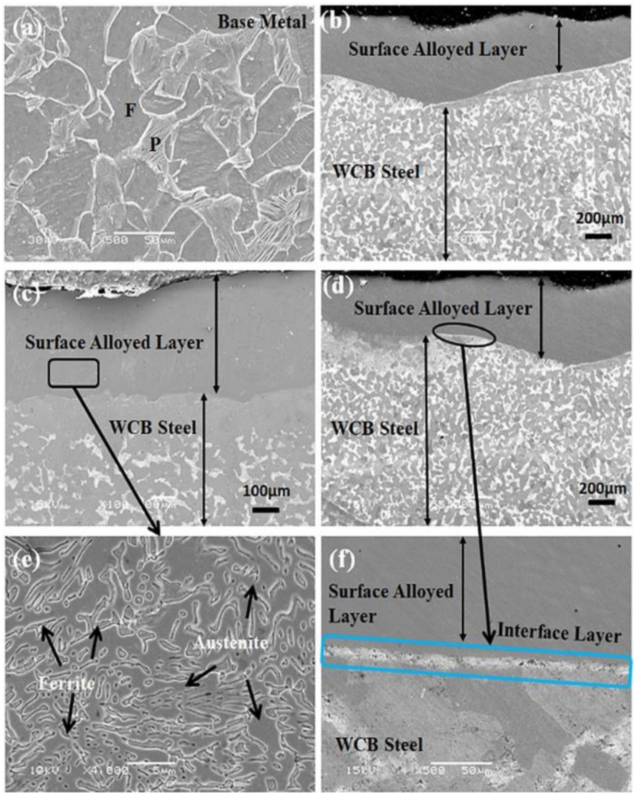


Figure 5. SEM micrograph of a base metal, (b d) BV1 surface alloyed layer, (c) BV2 surface alloyed layer in as-cast condition, (e) austenite–ferrite microstructure of the surface alloyed layer, (f) interface layer between surface alloyed layer and the base metal. All samples were in the as-cast condition.

The microstructure at the interface of the surface alloyed layer and the base metal suggests a good metallurgical bond. The microstructure in a typical surface alloyed layer (Figure6e) is composed of austenite(c) phases in the shape of elongated islands dispersed in the ferritic (a) matrix and free of precipitates. In addition, the morphology of the austenite phase ranged from elongate dislands to an equiaxed form. The EDS line scan results of surface alloyed sample BV3 (Figures7) show the change in the gradient of various alloying element content from the substrate to the surface alloyed layer. Table 3 lists the composition of the surface alloyed layer and the interface. Compared with the original composition of the WCB steel, a significant increase of nickel, chromium, Mo, Mn, and Si has been detected in a surface alloyed layer. The analyses were performed in regions ferrite (a phase) and austenite (c phase), indicated in the micrographs (Figure 6e). It was observed that the elements chromium and molybdenum are present in a higher percentage in the ferrite phase, since they are ferritizing elements, and nickel is present in a higher percentage in the austenite phases incent dissolves and stabilizes a ustenite.[13]

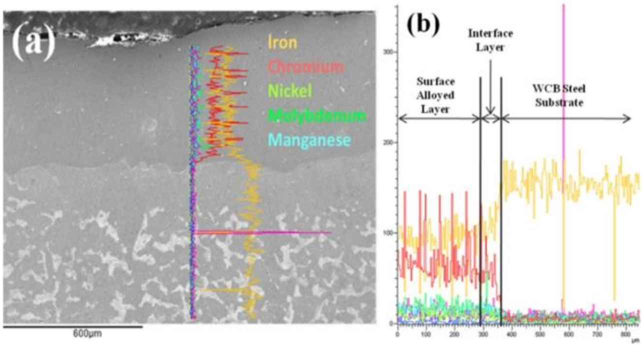


Figure6.(a) Location of the EDSlinescanonthecrosssectionoftheBV3surfacealloyedsample acrossthe base metal and surface alloyed layer. (b) Plot of elemental intensity vs distance in the EDS linescan.

The XRD analysis of the surface alloyed layer of the surface alloyed sample BV3 is shown in Figure 8. It confirms the presence of ferrite, austenite, and chromium oxide ($Cr_2O_3$) in the surface alloyed layer. The presence of $Cr_2O_3$is known to improve the corrosion resistance of the alloy.This oxide can form in ambient conditions; however, heattreatment of the alloy leads to the acceleration of the oxideformation. It should be noted that while there is a chance that all elements present in the system can form oxides(such as FeO, $Fe_2O_3$, $Fe_3O_4$, NiO) at high temperature, notall of these oxides can exist simultaneously in equilibriumwith one another. The selective oxidation chromium can beexplained by the standard free energy of formation and Ellingham's oxidation curve, as shown in Figure 9. It shows that $Cr_2O_3$ is more chemically stable than iron oxide significant scatter within the surface alloyed layer, suggesting that the distribution of alloying elements in the surface alloyed layer is quite uniform(Figure7).

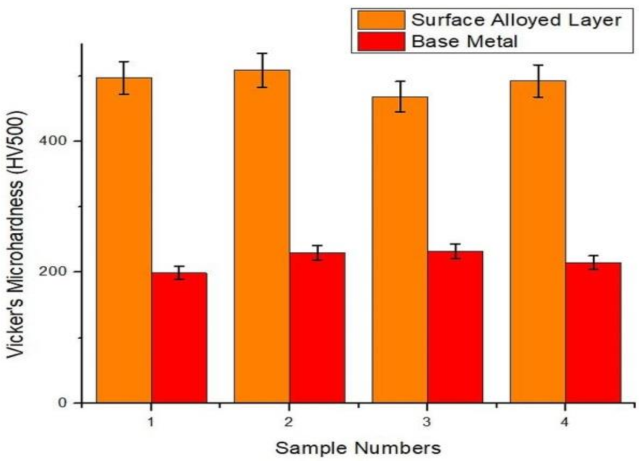


Figure 7.Comparison of the hardness of the surface alloyed layer and the base metal indicating a consistentincreaseintheas-castcondition.

## IV. CORROSION RESISTANCE

There are two ways to improve the corrosion resistance ofiron-based alloys: (1) to improve its thermodynamic stability by adding some alloying elements with higher thermodynamic stability like Ni and Cr to the solid solution to increase its electrode potential and to decrease the anodic activation and (2) to promote the formation of stable passivation on the surface and to improve its resistance on corrosion reaction by adding elements like Cr and Mo.Therefore, the large increases in the Ni and Cr content inthe surface alloyed layers as a result of surface alloying cansignificantly improve its corrosion resistance. In addition,the rise in austenite in the microstructure of the alloyed layer will also improve the corrosion resistance.

Table1.CorrosionRateValuesforSurfaceAlloyedSamplesandWCB

| Elementalcomposition (inwt%) | Surfacealloyed layer | Interfacelayer | WCB basemeta |
|---|---|---|---|
| Cr | 23.2 | 3.80 | 0.5 |
| Ni | 6.4 | 3.89 | 0.5 |
| Mo | 3.3 | – | 0.2 |
| Mn | 1.1 | 1.04 | 1 |
| Si | 0.7 | 0.54 | 0.6 |
| Fe | Balance | Balance | Balance |

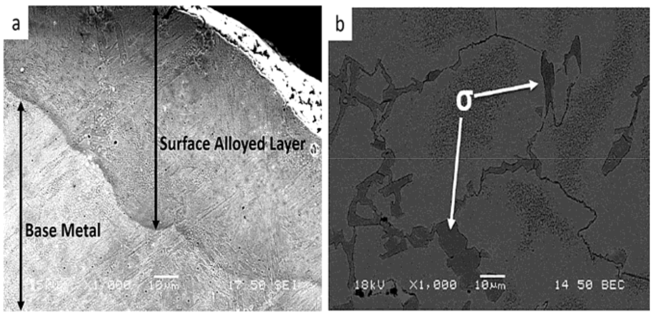


Figure8.(a)Theabsenceoftherphaseinthesurfacealloyedlayerofsurfacealloyedsample BV3aftersolutionannealingat850Cforaperiodof100seconds.
(b)Thepresenceofintermetallicrphaseinthesurfacealloyedlayerofsurfacealloyedsample BV3beforeheattreatment.

### Applications

It has been demonstrated that the novel cast surface alloying process produces a surface alloyed layer enrichedin several elements (including Ni, Cr, Mo, and Mn) on butterfly valve WCB steels and castings. The surface alloyed WCB castings are slightly more expensive compared to WCB steel castings, but they are much lower incost compared to through section stainlesssteel (as muchas $10-12 per pound). The scalable and more economical techniques for coatings and molds and cores with are fractory wash containing metal and ferroalloy powder for surface alloying could include flow coating, spray coating, dipping, and brush coating. This demonstrates the potential of reducing production costs of using surface alloyed WCB steels compared to through section stainless steel components. It also demonstrates that surface alloyed steel castings provide much more improved corrosion resistance, with only a marginal increase in the cost over plain WCB steel castings. This suggests several other potential applications of surface alloyed WCB castings in addition to butterfly valves, where corrosion and wear resistance higher thanthatofWCBsteelarerequired.

## V. CONCLUSIONS

The WCB steel butterfly valve sand castings were successfully surface alloyed with Ni, Cr, Mn, Si, and Mo by adding powders of nickel, chromium, ferrosilicon, ferro-manganese, and molybdenum to the mold coating. The surface of the WCB steel butterfly valve casting was enriched with upto 23.2 weight %Cr, 6.4 weight %Ni, 1.1weight % Mn, and 3.3 weight% Mo, during sand casting asa result of mixing of nickel, chromium, ferromanganese, and molybdenum powders to mold coatings. Austenite and ferrite were the primary phases observed in the as-cast surface alloyed layer. Samples from normalized and tempered surface alloyed butterfly valve castings made in thisstudy are likely to exhibit a 50% decrease in corrosion rateas compared to base metal WCB steel, as suggested by the linear polarization test conducted in this study. The surface alloyed WCB alloy castings are likely to have much higher wear resistance, as suggested by the higher hardness of the surface alloyed layer on the castings. The following are as require further work: developing quantitative relationships between processing parameters and the thickness, composition, phase structure, residual stresses, adhesion, surface finish of surface alloyed layers,and their influence on corrosion and hardness. The mechanisms of melting and dissolution of powders in mold coatings, formation of optimum solidification.

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