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Wear Properties of P/M Duplex Stainless Steels Developed from 316L and 430L Powders

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Abstract: In the present investigation two compositions of duplex stainless steels (DSS) were obtained from pre alloyed 316L and 430L powders along with controlled addition of Cr, Mo and Ni through powder metallurgy route. The prepared powder mixes have been compacted at 560 MPa and sintered in argon and nitrogen atmospheres at 1350^0C for 2 hours. The argon sintered duplex stainless steels have higher density increments in the range of 9-11% than the nitrogen sintered duplex stainless steels. Sintered DSS microstructures have been studied by optical microscope and Scanning Electron Microscope (SEM). The microstructure of nitrogen sintered steel contains lamellar constituents in the austenite-ferritic matrix, but argon sintered DSS has only biphasic structure of austenite and ferrite. . From the pin-on-disc experimental results, it is observed that the wear resistance of nitrogen sintered duplex steel samples has better wear resistance than argon sintered duplex steel samples due to the presence lamellar constituents such as chromium nitride with austenite and ferrite. The wear behavior of nitrogen sintered DSS are evident from SEM worn surfaces containing less debris and ploughs compared with argon sintered DSS.

Key words: Wear resistance, Sintering, Duplex Stainless steels, lamellar constituents.

1. Introduction

Powder metallurgy steel parts particularly show a new application to meet the requirements of end users. An alloy of Cr-Ni-Fe is quite interesting due to their attractive mechanical properties. Stainless steels are Cr-Fe based alloys that contains minimum of 12% chromium to prevent formation of rust in normal atmosphere. Austenitic stainless steels are non-magnetic and used for cryogenic applications but it has insufficient strength. Ferritic stainless steels have good tensile strength but limited corrosion resistance and toughness. Individually austenitic steels and ferritic steels reveal poor strength and inferior corrosion resistance however, the combination of ferrite and austenite structure exhibits excellent corrosion resistance, good strength and toughness. The bi-phase structured steels such as austenite and ferrite which has quite attractive due to their combined duplex phase microstructure. The sintered duplex stainless steels could be used in many off shore applications due to their excellent corrosion and mechanical properties [1-3]. The methods for obtaining the duplex microstructure steels are either mixing the elemental powders of Mo, Cr and Ni with ferrite-austenite alloyed powders in proper ratio or pre alloyed powder with the required duplex composition [4-6]. In order to achieve good wear properties, duplex stainless steels must be sintered at high temperature under controlled atmosphere [7-9]. Based on the composition, the P/M duplex steels must be cooled from sintering temperature with controlled cooling rate to avoid precipitations of intermetallic sigma phase [10]. Recent literatures stated that nitrogen addition in duplex stainless steel improves the wear and corrosion resistance properties for offshore and petrochemical applications. Garcia et. al (2008) reported that the wear resistance behavior of stainless steel was improved by sintering of duplex stainless steels under nitrogen –hydrogen atmosphere and concluded that nitrogen is an important alloying element which extends the passivity range [10]. Similarly some researchers reported that the wear resistance behavior of DSS can be improved by the presence of intermetallics or secondary precipitates [11]. The phase transformation in duplex stainless steel is the formation of sigma phase or chromium rich precipitates at intermediate temperatures due to the improper cooling rates. This secondary precipitate induces hardening, embrittlement and corrosion decay [14]. Lu et.al reported that the presence of such precipitates enhancing the wear resistance of duplex stainless steel with different manganese content [15]. In this present investigation the main objective is to study the microstructure and wear properties of duplex stainless steels developed from pre-alloyed powders such as 316L and 430L with and without addition of elemental powders and sintered in argon and nitrogen atmospheres.

2. Experimental Procedure

Duplex stainless steel of two different compositions has been prepared using water atomized 430L ferritic and 316L austenitic pre alloyed powders supplied by M/s Hoganas India Ltd. These base powders (AISI 316L and AISI 430L) were mixed with the addition of elemental powders such as Cr, Mo and Ni in the right quantity to obtain the chemical composition of duplex phase. These elemental powders have been procured from Inframat Advance Materials Ltd., United States. The chemical composition of duplex powder mixtures are presented in Table1. The elemental concentration of various metal elements of two different duplex stainless steels and their chromium and nickel equivalent numbers are shown in the table.2. The prepared mixtures such as DSS A and DSS B were located in the austenitic-ferritic area of the Schaeffer's diagram (Fig. 1). The above said duplex powder mixes were mixed by using the pre-alloyed powders with elemental powders through pot mill for 12 hours. The green compacts of 30mm diameter and 12 mm height were prepared by Universal Testing Machine at a pressure level of 560±10 MPa. The cylindrical green compacts were sintered in two different atmospheres such as nitrogen and argon at a temperature of 1350±10^{0}C for 2 hours. After sintering the compacts were cooled at a rate of 40^{0}C per minute. Density measurements of both green compacts and sintered compacts were taken by physical and mass dimensions to understand the effect of sintering atmosphere and chemical composition.

Table 1. Chemical composition of 430L, 316L grades and powder mixtures

Base Powder	**Elements by Wt. %**						
	Cr	C	Ni	Si	Mn	Mo	Fe
AISI 430L	16.56	0.012	---	1.20	0.10	---	82.02
AISI 316L	16.60	0.023	12.43	0.90	0.10	2.10	67.847
Powder Mixes							
DSS A	(50%316L+50%430L) by wt%						
DSS B	(45%316L+45%430L+4%Cr+3%Mo+3%Ni) by wt%						

Table 2. Chemical composition of investigated powder mixtures

Composition	**Elemental Concentration(%wt)**								
	Cr	**C**	**Ni**	**Si**	**Mn**	**Mo**	**Fe**	**Cu**	**Cr_{eq}**	**Ni_{eq}**
DSS A	16.5	0.01	6.2	1.0	0.10	1.1	Bal	---	19.2	6.81
DSS B	18.9	0.01	8.5	0.9	0.09	3.9	Bal	---	24.3	9.12

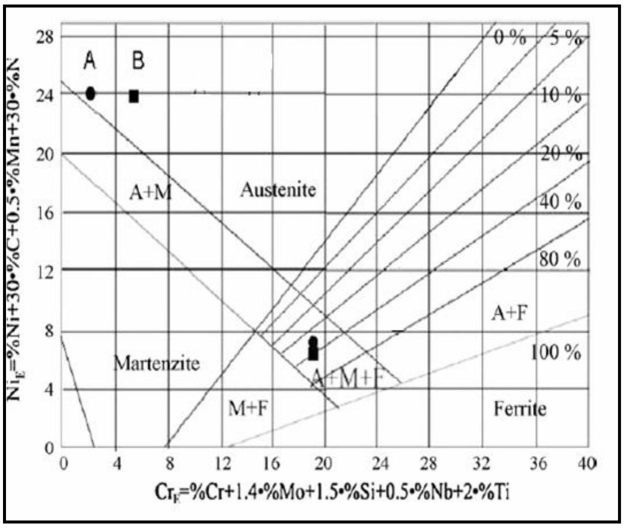

Figure 1.Schaffler's diagram indicating CrE and NiE for DSS A, and DSS B compositions [1]

Micro structural examination was performed with the help of Image analyzer and the intermetallics or secondary precipitates of phase was analyzed by Scanning Electron Microscope. Room temperature wear properties of sintered billets were carried out by using pin on disc apparatus. The size of the pin was 6 mm in diameter and 15 mm in length. The duplex stainless steels were used as the test material. The counter disc with 65 mm outside diameter and 10 mm thickness was fabricated using high carbon high chromium steel (die steel). The wear rate was calculated from the weight-loss measurements. The tests were carried out at 20N and 30N loads. To investigate the wear mechanisms of P/M DSS, worn surfaces and sub surface regions of wear pin were observed under SEM.

3. Results and Discussions

3.1. Densification studies

The density bar charts of duplex powder mixes sintered in two different atmospheres such as nitrogen and argon are shown in Fig 2 and Fig 3 respectively. From these results it is understood that the composition of the studied samples of steel has only marginal influence on the density improvements. The steel samples sintered in nitrogen atmosphere show 4-6% density increments irrespective of composition. However, the steel samples sintered in argon atmosphere reveals higher density increments in the range of 9-11%, which was reported in our previous investigation [1].

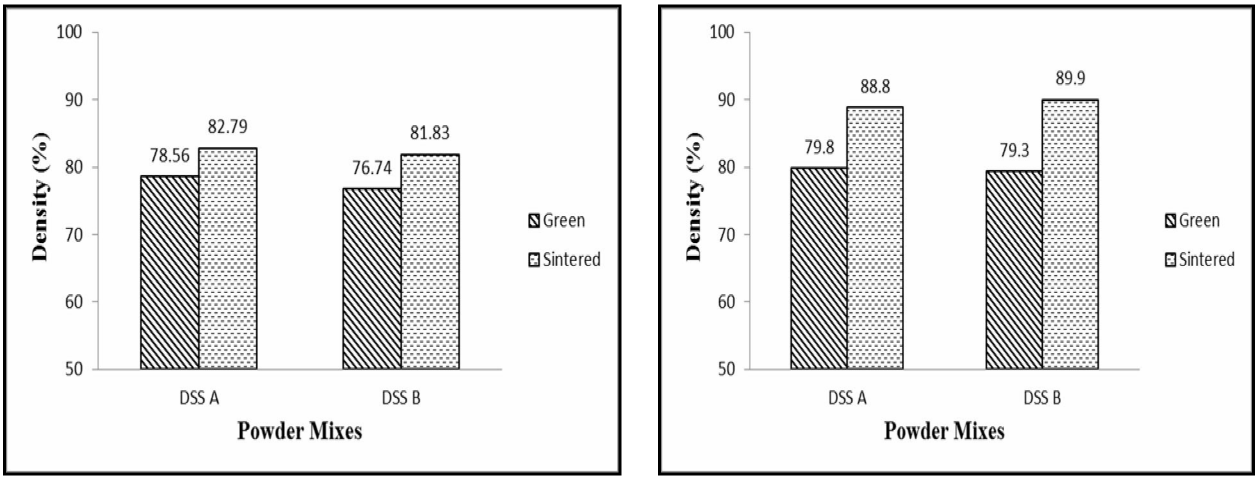

Figure 2 and 3. Percent theoretical density of studied samples under nitrogen and argon atmosphere sintering

The sinterability of studied steel samples is also determined in terms of densification parameter which is expressed as [11]. Fig 4 represents the densification parameter of studied samples sintered under two different atmospheres. The samples sintered in nitrogen atmosphere have lower sintered density when compared to the samples sintered in argon atmosphere. This is due to the formation of Cr_2N, which is immersed from the nitrogen atmosphere and in turn decreases the diffusion rate results in lesser sinter density.

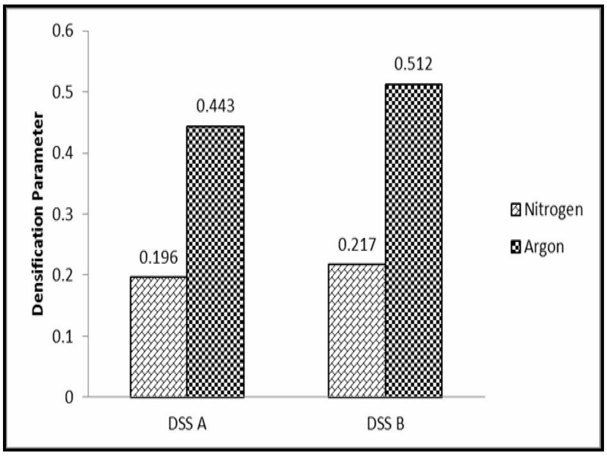

Figure 4. Densification parameter of samples sintered under nitrogen and argon atmosphere

3.2. Microstructure Evaluation

The optical micrographs of investigated samples such as DSS A and DSS B sintered in nitrogen and argon atmosphere are shown in Fig 3 and Fig 4 respectively. From Fig 5 it is observed that the samples sintered in nitrogen atmosphere contains lamellar constituents with austenite and was explained clearly in the previous investigation [1]. The lamellar constituent was treated as false pearlite, melted under high nitrogen gas pressure. It is a mixture of chromium nitride (Cr_2N) and ferrite, usually seen in Cr-Ni-Mn-Fe alloys [12]. The microstructure of samples sintered in argon atmosphere (Fig 4) is entirely different from samples sintered in nitrogen atmosphere. It is clear that there is no lamellar constituents and grain boundary nitrides, instead it indicates the balanced amount of ferrite and austenite phases, this was also reported in our previous investigation [1].From the fig. 6 the duplex composition DSS B contains the sigma precipitates at the grain boundaries of ferrite and austenite grain. Higher magnification Image (Scanning Electron Microscopic image) of samples sintered under nitrogen atmosphere as shown in Fig 7, which contains porosity with lamellar constituents.

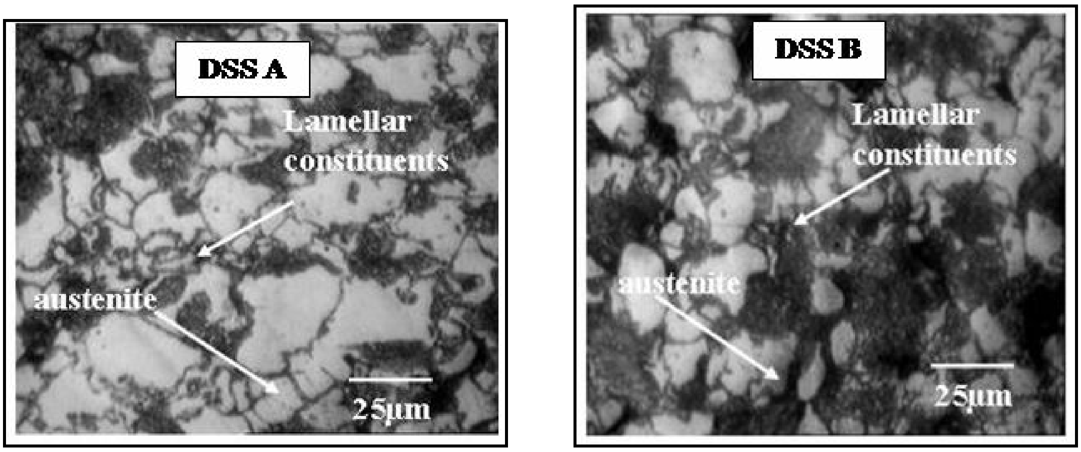

Figure 5. Optical Micrographs of samples sintered in nitrogen atmosphere [1]

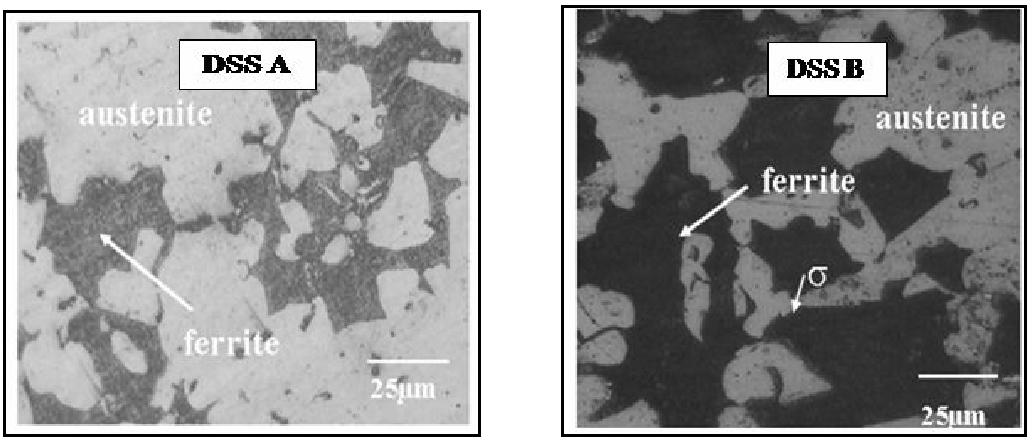

Figure 6. Optical Micrographs of samples sintered in argon atmosphere [1]

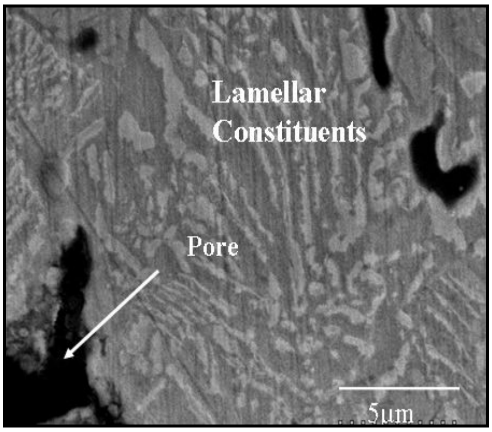

Figure 7. SEM – Micrograph of DSS A sintered in Nitrogen atmosphere

3.3. Wear studies

The wear rate of sintered DSS samples were measured by conducting wear studies using Pin-on-disc apparatus. Different loads of 20N and 30N is applied for constant sliding distance. The wear behavior charts of sintered DSS in different atmospheres with applied loads of 20 N and 30 N are shown in Fig 8 and Fig 9 respectively. From these figures it is observed that the wear rate of duplex samples is strongly influenced by the chemical composition and sintering atmosphere.

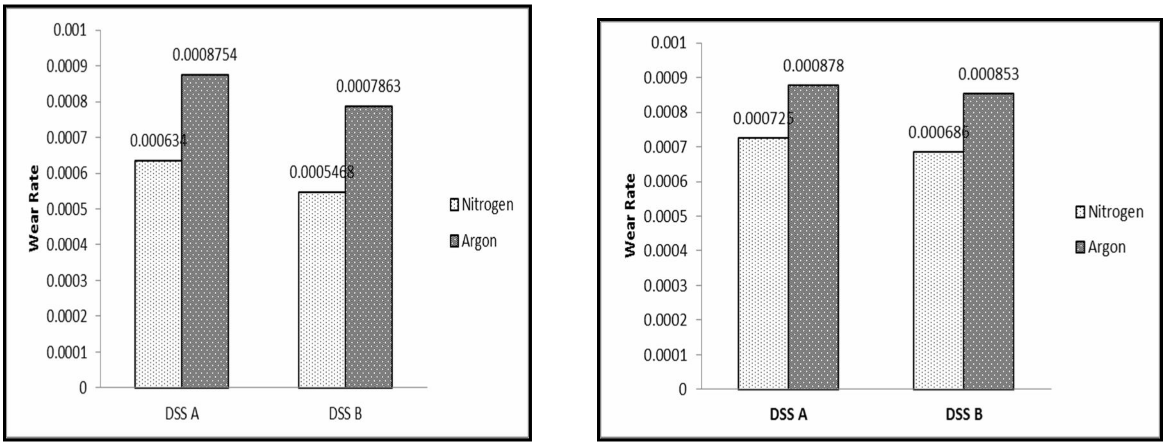

Figure 8 and 9. Wear rate of studied DSS samples sintered in different atmospheres at 20N and 30N load.

The samples sintered in argon atmosphere exhibits higher wear rate than the samples sintered in nitrogen atmosphere. The wear rate varies from 0.0005468mm^3/mm to 0.0008754mm^3/mm, especially the nitrogen sintered steel has the lesser wear rate (0.0005468 to 0.000634 mm^3/mm) than the argon sintered stainless steel (0.0007863 to 0.0008754 mm^3/mm).

The duplex stainless steels with compositions A and B sintered in nitrogen atmosphere reveal higher wear resistance than the argon sintered duplex steels. The steel sintered in nitrogen atmosphere promoted the chromium nitride phase, which enhanced hardness and wear resistance properties. Higher content of chromium in the DSS B composition enhanced the chromium equivalent number accordingly the corresponding microstructure contains more quantity of lamellar structures with chromium nitride. Hence nitrogen sintered DSS B sample has higher wear resistance property than the DSS A which is evident from the microstructure.

3.4. Worn Surfaces

Fig. 10 shows the SEM worn out surface of the nitrogen sintered duplex stainless steel. More debris with plough marking for DSS A and not much debris for DSS B, has been observed from the given figure. The ploughs which are presented in the worn out surface of DSS A, has parallel to the sliding direction. From the fractured surface analysis the wear mechanism allied with this material is plastic deformation.

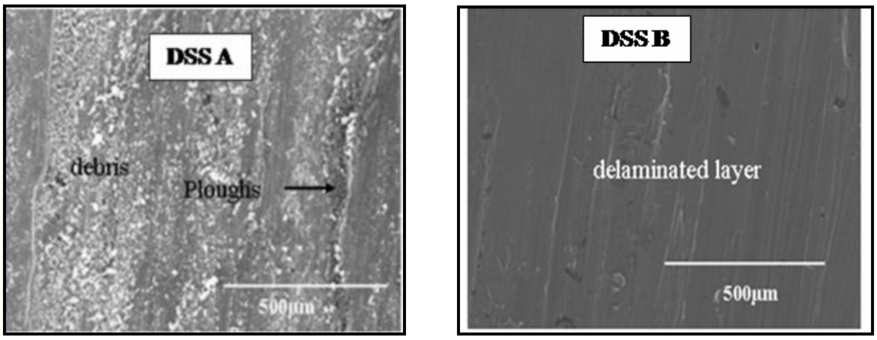

Figure 10. SEM Worn out surfaces of duplex samples sintered in nitrogen atmosphere

Duplex stainless steel with composition B has more wear resistance compared with the other stainless steel samples. The formation of more chromium nitride in the DSS B led to the enhanced resistance of wear .

The worn out surface of argon sintered duplex stainless steel (Fig 11) slightly different than the worn out surface of nitrogen sintered duplex steels. The mechanism linked with the worn out surface is plastic deformation. More amounts of ploughs and some pores for DSS A and formation of plateau and lipping (lateral spreading) for DSS B have been observed from Fig 11. Ploughs with pores are visible along the worn surface for the DSS A. In addition, highly layered structure, which is parallel to the sliding direction, exists on the surface with cracks.

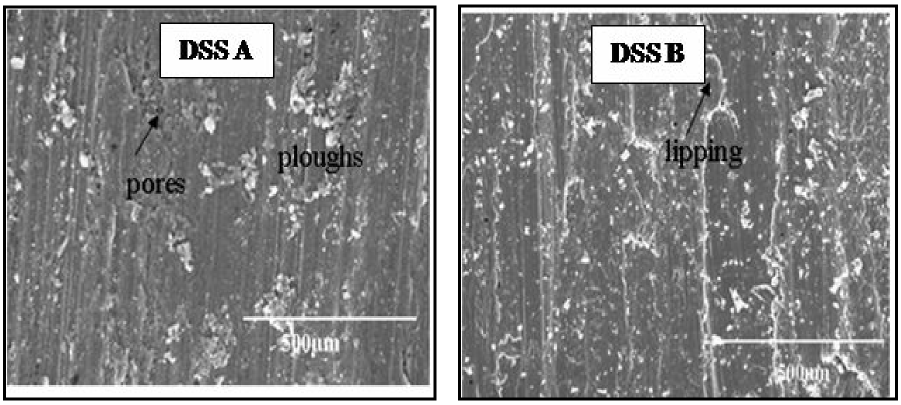

Figure-11. SEM Worn out surfaces of duplex samples sintered in argon atmosphere

4. Conclusions

In the present investigation, effect of sintering atmosphere on density, microstructure and wear properties were studied. The salient features of the current study are summarized as follows:

- The wear resistance of nitrogen sintered duplex stainless steel was more when compared to the wear resistance of argon sintered duplex steels due to the formation of more lamellar constituents with ferrite matrix.
- The duplex stainless steel with composition A has higher wear rate than the duplex stainless steel with composition B sintered in both the atmospheres such as nitrogen and argon due to more formation of ferrite.
- From the worn out surfaces of nitrogen sintered samples, it is observed that the composition A has more debris and ploughs but not much debris for composition B.
- From the worn out surfaces of argon sintered samples, composition A has some pores and more debris where as the formation of plateau and lipping for composition B has been observed.

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