ANALYSIS ON BEHAVIOR OF CUMULATIVE WEIGHT GROWTH FOR HVOF LOW EXPOSED OXIDIZED UNCOATED STEEL

[1]K.Baba Saheb, [2]N.Srikanth, [3]D Paramesh, [4]MD Naushad
[1,2,3] Assistant Professor, [4]UG Student, [1,2,3,4]Department of Mechanical Engineering, Kasireddy Narayanreddy College Of Engineering And Research, Hyderabad

ABSTRACT
The operating circumstances of power plant boilers are favorable for fire side corrosion in the regions of the super heater, reheated, and furnace wall, which has the effect of weakening the tube wall and causing early failure. As a result of combustion products changing their state of matter and turning into salts at high temperatures, corrosion can happen in a number of ways in coal-fired boilers. Chromium and molybdenum are the main alloy additions utilized in the fabrication of the low alloy carbon steels used in the boiler tube. Chromium does provide oxidation resistance by creating a passive oxide layer on the surface of the alloy, but the quantity in the boiler tube is insufficient to produce a protective exterior scale. Present materials being capable of resisting oxidation environments are highly alloyed and thus expensive. In search for cost effective solution for oxidation, various coating like thermal sprayed coatings have become more attractive. The high velocity oxy- fuel (HVOF) process belongs to the family of thermal spray process and as grown into a well-accepted industrial technology. This process has been shown to produce coating with better density, coating cohesive and bond strength than other thermal spray process.
HVOF spraying has been carried out using HIPOJET 2700 equipment, using super charging jet generated by combustion of liquid petroleum gas and oxygen mixture. The feed stock powder namely CoCrAlYTaCSi-Cr3C2 has been HVOF sprayed on boiler tube steels. The microstructure, physical and mechanical properties of coatings has been studied and characterized. Further, behaviour of the coated materials at high temperature is significant. Thermocyclic oxidation studies in the oxidation environment at 700˚C for 50 cycles are carried out. It is seen from the results that the cumulative weight gain for the HVOF coated steel is significantly lower than that of uncoated steel subjected to oxidation.
Keywords: online shopping, convenience, web site quality, awareness

INTRODUCTION
The demands of today's industry cannot be met by a single material, thus a composite system using a base material that provides the required mechanical strength is used instead. Corrosion is the term used to describe the deterioration of metals caused by a chemical reaction in the presence of the immediate environment.
When surfaces covered with a thin coating of few environments are subjected to high temperature circumstances, oxidation is the rapid oxidation that results. Common examples of this type of oxidation are gas turbines, boilers, internal combustion engines, etc. Coating materials have been created to reduce this oxidation, and other coating methods have also been researched. In this work, an effort has been made to examine the mechanical, physical, and micro structural characteristics of the high velocity oxy fuel sprayed on boiled tube steels.

Review of Literature
The total economic loss from all types of corrosion in India is approximately $6500 USD [1]. Hot corrosion, which occurs as a result of elevated temperatures, results in rapid oxidation. It is caused by the formation [2]. The sulphur content of the gases reacting with the metal's surface caused fire side corrosion. The coal also contains vanadium, which when burned produces V2O5. This reacts again with sodium sulfate to generate vanadates, which are very corrosive at high temperatures [3]. The presence of sulphur in low-quality coal causes SO2 to be produced during combustion, which then oxidizes to produce sulfur trioxide, which reacts

with water vapor [4]. According to a research by Shih et al., corrosion appears at high rates when metal and nonmetal are restricted by a thin layer of watery salt at a high temperature in a gas environment. Such corrosion is referred to as hot corrosion. The failure of the machine component is brought on by the atmosphere's acidic nature, which can produce terrible conditions with gaseous oxygen, carbon, and sulfur [5]. Chatha et al. [6– 7] computed the oxidation and erosion performance of 75Cr3C2-25NiCr and Ni-20Cr alloy coating on substrate T91 at 900°C for 1500-hour intervals, and found that Ni-20Cr coated steel produced superior results. Due to the presence of Cr2O3 in the top oxide scale, it happened. Sidhu et al. [8–10] formulated Ni and Co on boiler steel tube with thermal spray coating method. When satellite-6 coating was put to the substrate GrA1, the researchers noticed the maximum oxidation and erosion resistance.

Experimental section

Substrate Material

The substrate boiler tube steels for the study were procured from M/S Mishra Dhatu Nigam Limited (MIDHANI). The chrome moly steel (designated as ASTM-SA213-T22) which is being used as material for water wall, super heater and reheater tubes in coal fired thermal power plants in northern part of India has been used as a substrate material in the present study. The nominal composition of the boiler tube steels is given in Table 1.

Table No.1: Chemical composition (Wt. %) of substrate alloy T22.

Alloy Grade (ASTM code)	Chemical Composition (wt. %)							
	Fe	Su	Cr	Ph	Mo	Mn	Si	C
SA213-T22	Bal.	0.025	2.55	0.025	1.10	0.52	0.50	0.14

Coating material

Two types of commercially available feedstock materials have been used in the powder form. This has been used to as a spray coating material on three different types of substrate materials using High velocity oxy fuel coatings (HVOF). The details of the chemical composition and particle size of powder is reported in Table 2.

Table No.2: Chemical composition and particle size of coating powder.

Coating powder	Chemical Composition (Wt. %)	Particle size
CoCrAlYTaCSi+Cr3C2	70%CoCrAlYTaCSi + 30%Cr3C2	15 - 45 μm

Results and Discussion

Thermo gravimetric studies

The macrographs of the uncoated T22 steel subjected to cyclic oxidation in air for 50 cycles are shown in Fig 1. The uncoated alloys developed a dark grey colored oxide scale.

The plots of cumulative weight gain (mg/cm^2) as a function of time expressed in number of cycles are shown in Fig 2. The weight gain for the T22 steel at the end of 50 cycles are found to be 16.89mg/cm^2 respectively. Clearly, the T22 steel showed a weight gain during the cyclic oxidation studies. Further, the weight gain square (mg^2/cm^4) data has been plotted as a function of time, as shown in Fig 3, to establish law governing the oxidation. This plot shows the observable deviation from the parabolic rate law for the T22 steel, which indicate that the oxide films were poorly protective at 700°C. The parabolic rate constant kp was calculated by a linear least-square algorithm function in the form of $(\Delta W/A)^2 = kp\ t$, where $\Delta W/A$ is the weight gain per unit area, and t is the oxidation time in seconds. The kp for the T22 steel are $16.92 \times 10\text{-}10 g^2\ cm^{-4}\ s^{-1}$ respectively.

Figure 1: Macrographs of uncoated bare boiler T22 steel subjected to cyclic oxidation in air for 50 cycles at 700°C

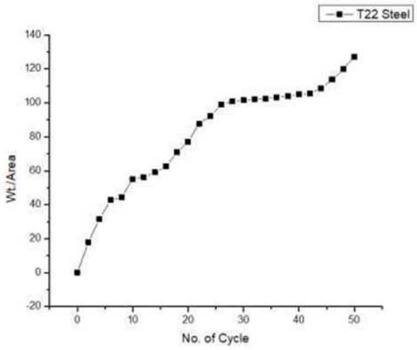

Figure 2: Weight gain vs. number of cycles plot for uncoated T22 steel subjected to cyclic oxidation for 50 cycles in air at 700°C

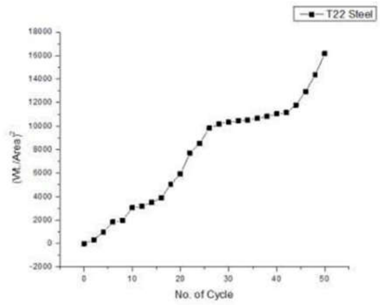

Figure 3: (Weight gain/area) ^{2} vs. number of cycles plot for uncoated T22 steel subjected to cyclic oxidation for 50 cycles in air at 700°C

X-ray diffraction analysis

The X-ray diffraction pattern for the steels, after exposure to air at 700°C for 50 cycles is compiled in Fig 4. As obvious from the composition, all the steels show Fe2O3 as the major peak. The T22 steel showed minor peaks of Cr2O3, MoO, FeCr2O4 and SiO2

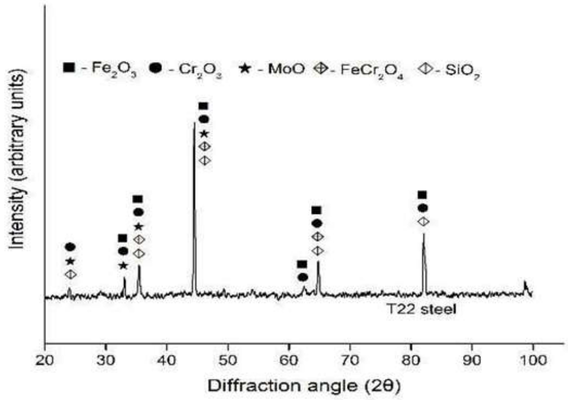

Figure 4: X-ray diffraction patterns for the uncoated T22 steel subjected to cyclic oxidation for 50 cycles in air at 700 ºC

SEM/EDX analysis

The SEM micrograph showing the scale morphology along with the EDAX analysis is shown in Fig 5. The T22 steel consists of iron oxide as the main constituent in the oxide scale. The surface scale formed on the T22 steel shows cracks.

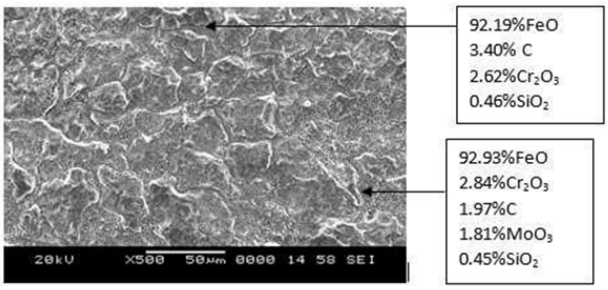

Figure 5: Surface scale morphology and EDAX point analysis for the uncoated T22 steel subjected to cyclic oxidation for 50 cycles in air at 700°C.

Uncoated T22 steel discussion

The XRD results show an outer layer of scale which mainly consists of Fe2O3 in T22 steel. The weight gains for T22 steel during oxidation studies are found to be less than.

The scale formed on the T22 steel was found to be fragile and cracked from centre of the sample. It is a well-known fact that the stresses developed due to a higher volume of oxides formed on the metal leads to scale cracking. The attainment of critical stress to cause scale rupture may be related to the critical thickness. The difference in the thermal coefficients of the oxide scale and the metal also contribute to the development of cracks in the scale. These cracks help in the internal oxidation and spalling of the scale.

Oxidation Study of CoCrAlYTaCSi+Cr3C2 coating

Thermogravimetric studies

Macrograph of the HVOF sprayed CoCrAlYTaCSi+Cr3C2 coating on T22 steel subjected to cyclic oxidation for 50 cycles at 700°C are shown in Fig 6. The oxide scale formed on the surfaces of the CoCrAlYTaCSi+Cr3C2 coated steel is found to be compact, adherent and no tendency for spalling. This indicates that the coatings can sustain the thermal shocks owing to heating and cooling (cyclic oxidation), which serves as an index for good adhesion and anti-spallation capability of the coatings. The plots of cumulative weight gain (mg/cm2) as a function of time expressed in number of cycles are shown in Fig 7. The total weight gain value for the coated T22 steel at the end of 50 cycles of oxidation studies are found to be $0.01 mg/cm^2$ respectively. Further, the weight gain square ($mg^{2/}cm^{4}$) versus the number of cycles are plotted in Fig 8. The parabolic rate constant kp was calculated by a linear least-square algorithm function in the form of $(\Delta W/A)^2 = kp\ t$, where $\Delta W/A$ is the weight gain per unit area, and t is the oxidation time in seconds. The coated steel show parabolic behaviour and the kp for the coated T22 steel are found to be $0.0919 \times 10\text{-}15 g^2\ cm^{-4}\ s^{-1}$ respectively.

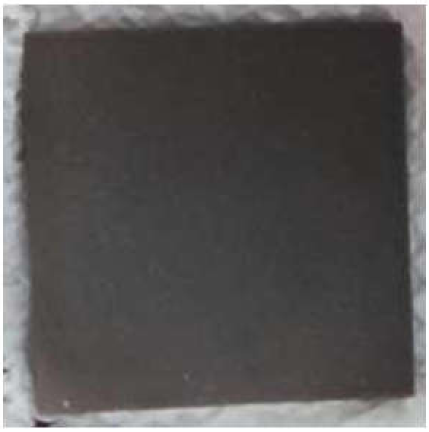

Figure 6: Macrograph of the CoCrAlYTaCSi+Cr3C2 coating subjected to cyclic oxidation in air for 50 cycles at 700°C for T22 steel.

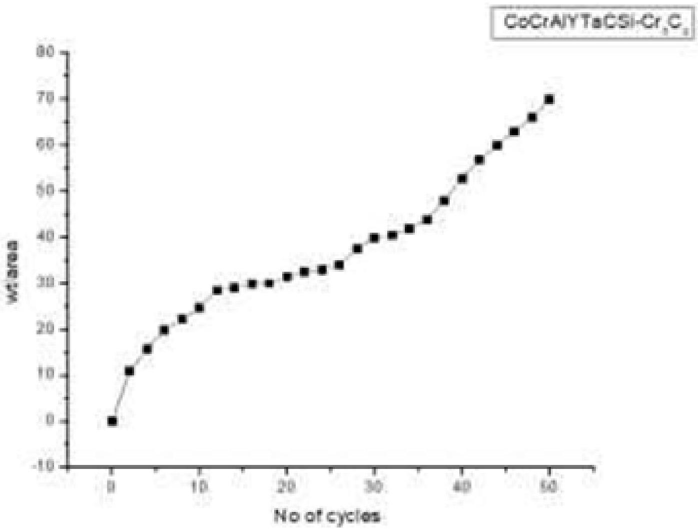

Figure 7: Weight gain vs. number of cycles plot for CoCrAlYTaCSi + Cr3C2 Coated T22 steel subjected to cyclic Oxidation for 50 cycles in air at 700°C.

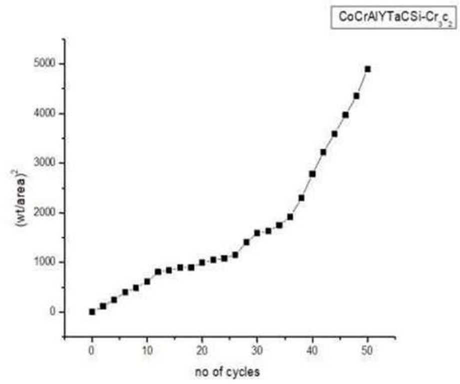

Figure 8: (Weight gain/area) ^{2} vs. number of cycles plot for CoCrAlYTaCSi+Cr3C2 coated T22 steel subjected to cyclic oxidation for 50 cycles in air at 700°C.

SEM/EDAX Analysis

The surface morphology (Fig 9) of the oxide scale formed on the surface of CoCrAlYTaCSi+Cr3C2 coated steel is thick, continuous, and non-uniform consisting of voids. Fig.9 shows the surface morphology of oxide scale formed on the oxidised CoCrAlYTaCSi + Cr3C2 coated T22 steel. Oxide scale consists of spherical globules dispersed in the non-uniform matrix. The EDAX analysis on the spherical globules revealed the possibility of formation of oxides and carbides of tantalum and chromium (35.73%Ta, 10.04%Cr, 28.64%C, and 16.46%O) as the main constituent along with YO (8.03%Y) and the EDAX analysis on the matrix showed similar morphology composed of oxides and carbides of tantalum and chromium (37.44%Ta, 17.08%Cr, 21.57%C, and 19%O) as principal phases along with a minor amount of YO (4.87%Y).

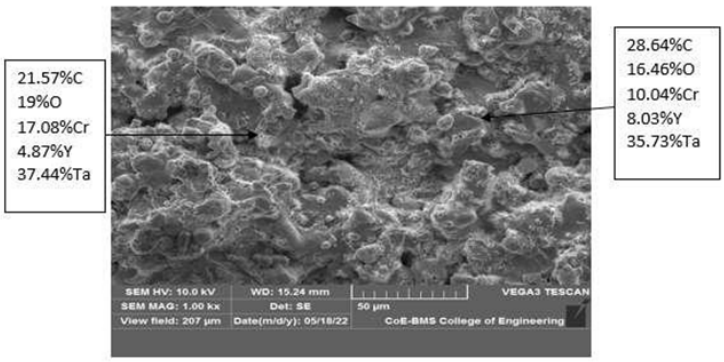

Figure 9: Surface scale morphology and EDAX point analysis for CoCrAlYTaCSi+Cr3C2 coated T22 steel subjected to cyclic oxidation at 700°C

X-ray Diffraction Analysis

X-ray diffraction patterns of the oxide scale formed on the surface of oxidized CoCrAlYTaCSi+Cr3C2 coated T22 steel after cyclic oxidation in air at 700°C have been compiled in Fig 10. The X-ray diffraction pattern for CoCrAlYTaCSi+Cr3C2 coated T22 steel shows the phases of Cr2O3, Fe2O3 along with the formation of intermetallic like MoO, SiO2 , and FeCr2O4.

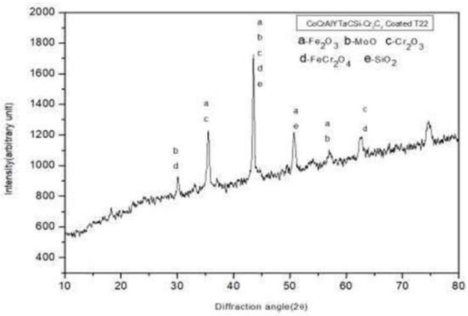

Figure 10: X-ray diffraction patterns for CoCrAlYTaCSi+Cr3C2 coated T22 steel subjected to cyclic oxidation in air for 50 cycles at 700°C

CoCrAlYTaCSi+Cr3C2 coating discussion

Weight gain data for HVOF sprayed coated and bare steels obtained from the oxidation data, the plots clearly indicate that the coated T22 steel follow a parabolic rate law up to 50 cycles, the values of parabolic rate constant Kp was calculated by a linear least-square algorithm function in the form of $(\Delta W/A)^2 = kp \times t$, where $\Delta W/A$ is the weight gain per unit area, and t is the oxidation time in seconds. The parabolic rate constant (kp) for the coated steels is lower when compared to the uncoated steels, hence coated steels exhibit lower oxidation rates. Weight gain for the coated T22 steel is less when compared with the uncoated steels, indicating that the coating acts as a diffusion barrier to the oxidizing species in air environment. The overall weight gain after 50 cycles of air oxidation for CoCrAlYTaCSi+Cr3C2 coated T22 steel are 0.01mg/cm^2 respectively. The overall weight gain of 16.89 mg/cm^2 was observed for the T22 steel respectively.

CONCLUSION

The deposition of CoCrAlYTaCSi + Cr3C2 alloy coatings on boiler tube materials has been effectively accomplished using high velocity oxy-fuel thermal spraying with liquid petroleum gas as the fuel gas.
An extensive spalling of oxide scale was seen on the uncoated specimen, which experienced a greater degree of oxidation. Iron oxide is the primary component of the oxide scale that forms on the specimen.
The total weight increase for the HVOF-coated T22 boiler materials is much less than it would be for an untreated specimen exposed to 50 cycles of oxidation in an atmosphere at 700°C. All of the coated specimens have the distinctive thick protective oxide scale that gives them resistance to oxidation in the specific air environment. This scale is made up of oxides and spinel oxide, which are the active ingredients in the coating. Based on the Thermo gravimetric data, the relative oxidation resistance of the CoCrAlYTaCSi + Cr3C2 is greater.

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