STUDIES ON OXIDATION AND WEAR RESISTANCE OF HARD SURFACING PRODUCED BY GAS THERMAL SPRAY OF MODIFIED NICKEL BASE EUTECTIC ALLOY POWDER

P. K. Ghosh*, D. K. Dwivedi, and P. S. Mishra*****

***Welding Research Laboratory, Department of Mechanical Engineering, University of Roorkee, Roorkee**
****Department of Mechanical Engineering, Regional Engineering College, Hamirpur**
*****Department of Materials and Metallurgical Engineering, University of Roorkee, Roorkee**

ABSTRACT

A commercially available Ni base eutectic alloy powder (EWACI005EC) was modified by mechanical mixing of 2wt.% Al powder with it. Hard surfacing of mild steel substrate was carried out by gas thermal spraying of both the original & modified powders. Oxidation resistance of the hard surfacing produced by using both the original & modified powders was studied under constant heating at temperatures of 800, 850 and 900°C for 8 hours and also under cyclic heating up to 15 cycles where, each cycle was designed as heating for a period of 2 hours at temperature of 800°C followed by cooling down to temperature of 300°C. The characteristics of microstructure and hardness of base metal and both the coatings of original and modified powders were studied. Wear resistance of the hard coatings of both the powders were studied at ambient temperature using "PIN on DISC" wear testing method at nominal loads of 2.5 and 3.5 kg. It was found that at all the test loads, the coating of the original powder is having comparatively better wear resistance than that of the coating of the modified powder. Under ihe cyclic heating original powder coating was marked to be comparatively better oxidation resistant than the modified powder coating. But, at a given temperature the hard coating of the modified powder was found comparatively better oxidation resistant than the same produced by spraying the original powder.

Key words : Thermal spraying, Ni base eutectic alloy powder, modification of alloy powder, hard surfacing, micro structure, hardness, wear, oxidation resistance.

INTRODUCTION

Hard surfacing is largely used to deposit a wear resistant coating either on a worn out or new component which has to be subjected to wear in service [1]. Depending upon desired thickness of coating, the hard surfacing is commonly carried out by gas thermal spraying of powder, plasma spray, weld deposition and weld cladding for applying a thick (>50 μm) coating of harder material on a comparatively softer and tougher substrate The thermal spraying process is one of the most versatile technique used for application of a moderately thick (upto about 1.5mm) coating of material having resistance to wear and oxidation or corrosion (2]. The properties of gas thermal spray coating are influenced by various factors [3] such as process parameters, surface treatment of substrate and physical and chemical characteristics of powder. The abrasive wear of a hard material is primarily defined as removal of material from its surface by means of mechanical action, which is to a large extent dictated by the oxidation resistance of an alloy at high temperature applications. With the increasing demand of high temperature applications as turbines engines etc., the studies on oxidation resistance of an alloy have gathered tremendous importance. Resistance to oxidation of any metal at high temperature primarily depends upon the nature of oxide film/scale formed at its surface. If the scale is loose and porous, oxidation will continue until whole section of metal is oxidised otherwise, in case of an adherent and non porous oxide layer, it will act as protective cover to the underlying metal [4].

In case of dry and hot gas corrosion of turbines/engines, so called $MCrAl_y$ alloys are commonly used as protective coating (M generally stands for Ni, Co and Fe), where the desired protection is attributed to formation of a thin oxide scale on it during operation at elevated temperatures. Along with their resistance to oxidation some other properties of these coatings are also intended as their high strength, hardness and toughness at elevated temperature [5]. During deposition of fhe powders by thermal process, various types of metallurgical transformations in the deposits are inevitable, depending upon chemical composition of the powder and thermal cycle ot the process, especially dictated by the cooling rate. These transformations leading to formations of various phases, precipitation of eutectic or any other inter-metallic compounds at the grain boundaries largely governs the chemical and mechanical properties of the coating [6].

In the context of the role of powder characteristics on wear resistance of hard coating, an investigation has been carried out to study the effect of compositional modification of a standard Ni base eutectic alloy powder on improvement in oxidation and wear resistance of hard surface, produced on a mild steel substrate by gas thermal spray process, especially in reference to the cyclic heating simulated to some service condition leading to dry and hot gas corrosion of turbines/engines. The wear resistance and abrasion mechanisms of the hard coating have been studied with respect to its composition, oxidation resistance, hardness and microstructure The performance of the coatings of the modified powders has been compared to that of the coating produced by using a commercially available Ni base eutectic alloy powder.

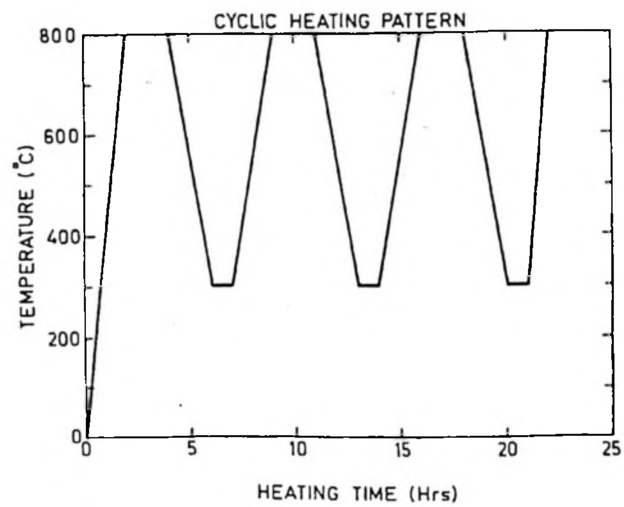

Fig.1: Schematic presentation of the cyclic heating pattern.

EXPERIMENTAL

The hard surfacing of 5 mm thick mild steel sheet was carried out by gas thermal spraying of modified and commercially available nickel base eutectic alloy powders (EWAC 1005 EC). The modified powder was developed by mechanical mixing of about 2.0 wt.% aluminium powder with the nickel base eutectic alloy powder. The modified powder containing aluminium coated nickel base eutectic powder was produced by vigorous processing of the powder inside a ball mill using steel balls ot weight approximately 20 times of the weight of the powder mixture.

The gas thermal spraying of the powders was carried out using a neutral oxy-acetylene flame at a pressure of oxygen and acetylene as 3.0 and 1.2 kg/cm respectively. Prior to thermal spray the substrate surface was mechanically cleaned and preheated to 300°C. The spraying was performed at a torch speed of 12 cm/min by maintaining a gap of 12 mm between the torch and the substrate under vertical placing of the torch.

The transverse sections of the coated specimens were prepared by standard metallographic procedure and etched by dipping in a solution containing glycerol (5 cc), acetic acid

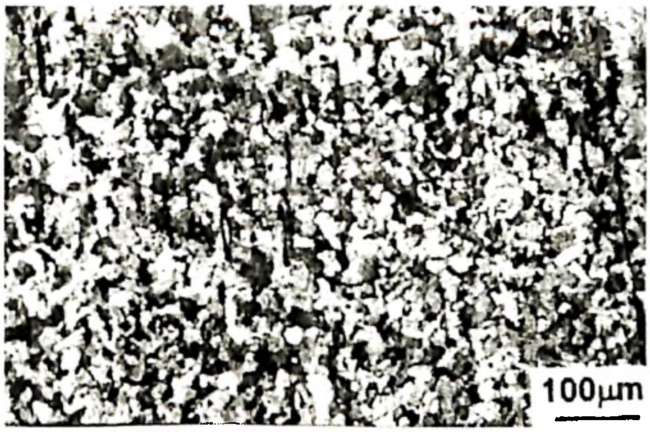

Fig.2: Typical microstructure of the mild steel base metal.

(10 cc), nitric acid (10 cc) and hydrochloric acid (15 cc). The microstructures of both the coatings of the unmodified and modified powders were studied under optical microscope and compared. Hardness of the base metal and the coatings was measured by vicker's diamond indentation at a load of 5 kg. The distribution of hardness on specific microstructural features of the coatings was also studied by vicker's microhardness indentation at a load of 10 g.

The wear characteristic of the coating was studied on "PIN ON DISC' type wear testing machine by sliding the coated face of the specirnens of size 30x3x50 mm on a steel disc. The wear tests were performed at different normal loads of 2.5 and 3.5 kg by sliding the coated samples through different distances, as a function of sliding time of a wear track of diameter 88 mm rotating at a speed of 300 r.p.m..

The loss in weight of the specimen due to sliding was evaluated as a measure of wear of the coating. The oxidation behaviour ot the coatings was studied under normal heating and cyclic heating by keeping the coated specimens of size 9x9x30 mm inside a muffle furnace at a stretch for a period of 8 hours at temperatures of 800, 850 and 850 °C and for cyclic heating up to 15 cycles where, each cycle was designed as heating for a period of 2 hours at temperature of 800°C followed by cooling down to temperature of 300°C for 1 hour as schematically shown in Fig 1. The gain in weight per unit area of the coating was evaluated by measuring the weight and graphical estimation of surface area of the specimen, which indicates the ability of coating to withstand at high temperature. All the tests were repeated with the coating produced by thermal spraying of the modified powder.

RESULTS AND DISCUSSIONS

The microstructure of the base plate has been found to consist of ferrite and pearlite (Fig. 2) as the common feature of mild steel. The typical microstructures of thermal spray coatings of the original and modified powders presented in Fig. 3 (a and b) respectively reveals the flawless interface and sound coating having practically negligible amount of porosity. In a close look on the microstructure of the coatings at higher magnification, the original powder coating (Fig. 4(a)) shows the presence of cellular structure in the matrix with a comparatively thicker layer of eutectic (marked by arrow) at the grain boundary whereas, the precipitation of eutectic (marked by arrow) at the grain boundary of the comparatively finer co-axial dendritic matrix of the modified powder coating has been in general found (Fig. 4(b)) to become comparatively thinner due to modification of powder by addition of aluminium.

The overall hardness of the base metal and the coatings of the original and modified powders are measured as 133 ± 6, 567 ± 60 and 300 ± 15 VHN respectively. The hardness distribution in the matrix, in reference to the locations of the grain boundary eutectic and over the grains, of the coatings of the original and modified powders has been found as (783 ± 120 and 245 ± 15 VHN) and (270 ± 10 and 310 ± 18 VHN) respectively. This may have extended a positive contribution to improve the wear resistance of modified powder coating because

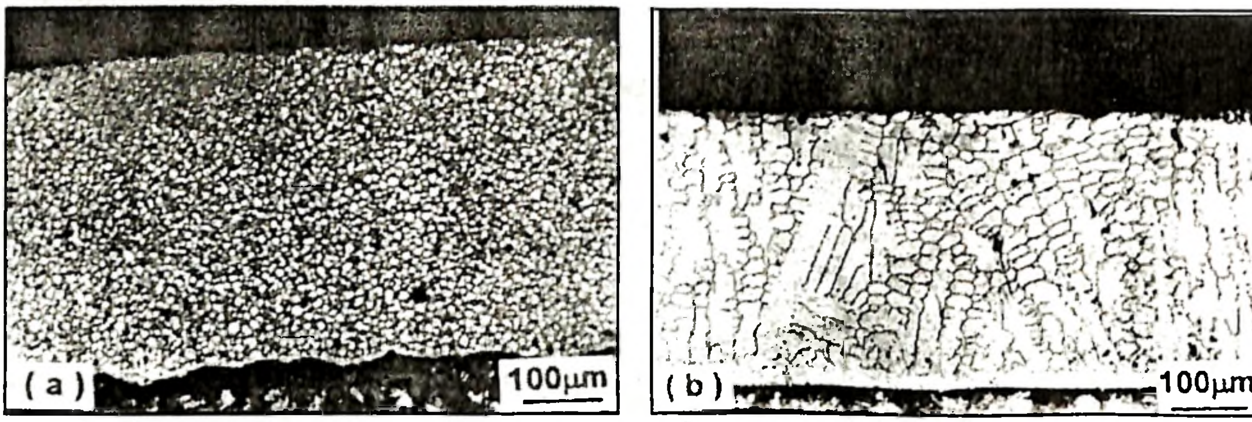

Fig.3: Typical microstructures of the thermal spray coatings and interfaces of the (a) original and (b) modified powders.

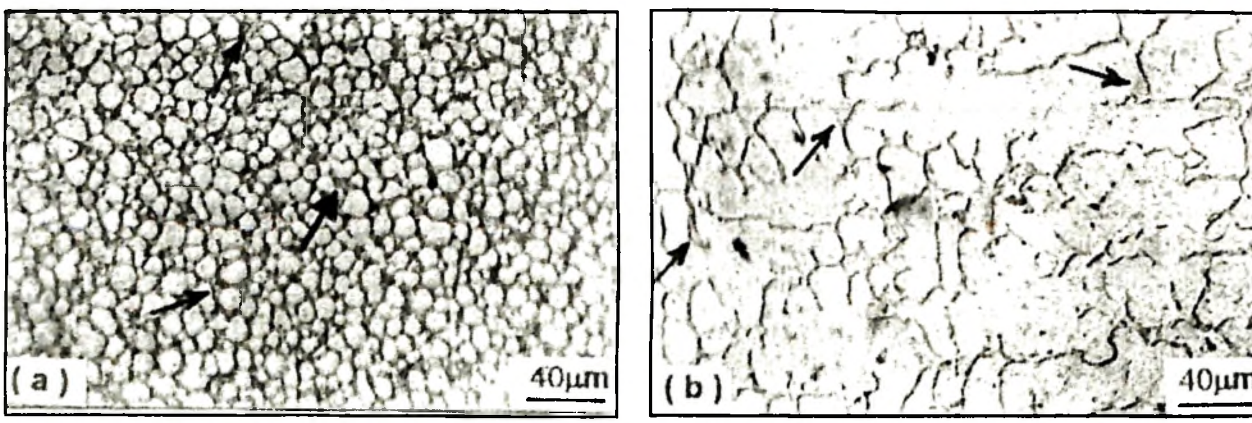

Fig.4: Typical morphology of both the coatings revealed at higher magnification (a) the original powder coating and (b) modified powder coating.

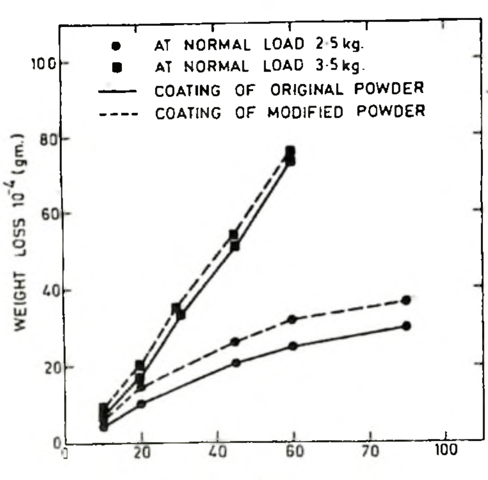

Fig.5: At a given normal load of 2.5 and 3.5 kg the nature of variation in wear characteristics of the hard coatings of the original and modified powders with the increase in time of sliding.

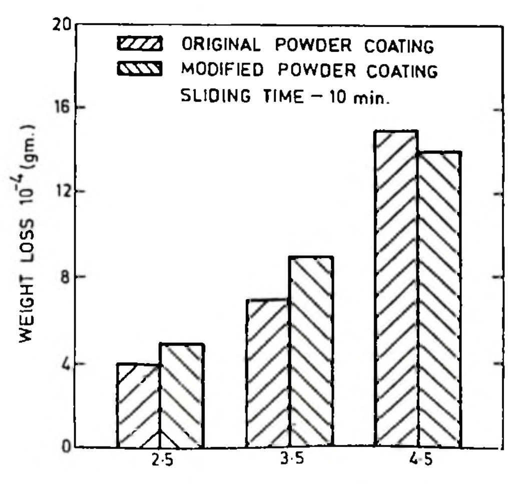

Fig.6: At a given sliding time of 10 minutes the effect of increase in normal load from 2.5 to 4.5 kg on the weight loss due to wear of both the coatings of the original and modified powders.

the hard thick eutectic at grain boundaries, as observed in the coating of the original powder, reduces the wear resistance of the matrix due to chipping of the thick layer of eutectic at grain boundaries. However, the wear resistance of hard coating is also governed by other characteristics of the matrix as discussed later.

During wear test under all the normal loads, it is observed that there exists a high initial frictional drag force which reduces with the increase in sliding distance at higher time followed by gaining a stability. This may have primarily happened due to breaking/blunting of asperity on the coating surface. At a given normal load of 2.5 and 3.5 kg the wear characteristics of the hard coatings of the original and modified powders in respect to the time of sliding at ambient temperature has been shown in Fig. 5. The figure shows that at the lower load of 2.5 kg the wear loss of both the coating of the original and modified powders becomes practically stable after sliding a distance covered in time beyond about 80 minutes, whereas at the higher load of 3.5 kg the wear loss of both the coatings has been found to be continuously enhanced significantly with the increase of sliding beyond 80 minutes. The figure also depicts that the wear characteristics of both the coatings of the original and modified powders are practically same, with a tendency of undergoing relatively higher wear loss in case of using the modified powder, especially at the lower load of 2.5 kg. However, at a given time

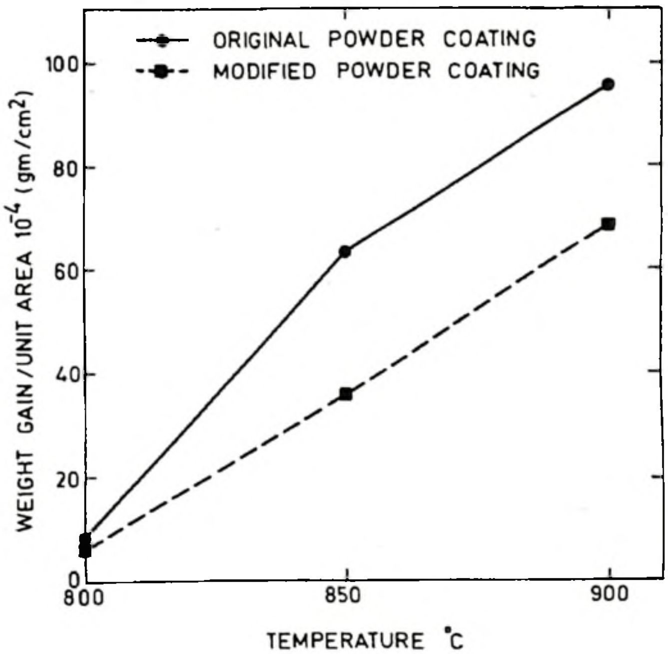

Fig.7: The effect of uninterrupted heating at different elevated temperatures on the weight gain due to oxidation behaviour of the coatings of the original and modified powders.

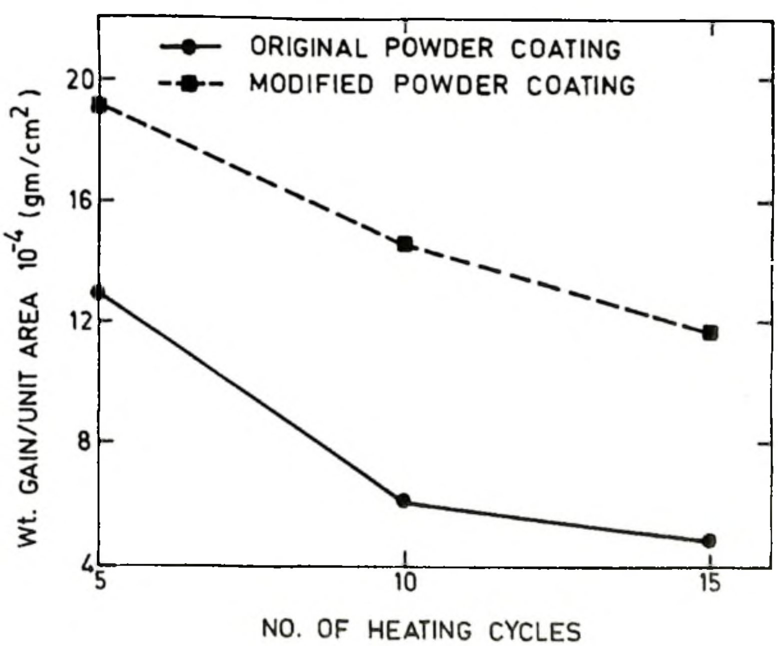

Fig.8: The effect of cyclic heating at elevated temperature on the weight gain due to oxidation behaviour of the coatings of the original and modified powders.

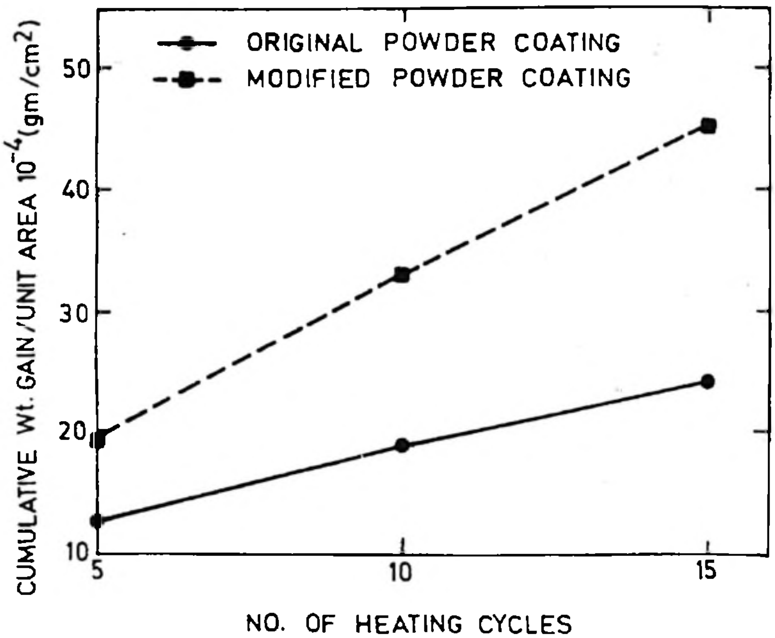

Fig.9: Cumulative weight gain per unit area of the coatings with the increase in number of heating cycle.

of sliding of 10 minutes the increase in normal load from 2.5 to 4.5 kg has been found to enhance the weight loss due to wear of both the coatings significantly, as shown in Fig. 6.

The oxidation behaviour of the coating under constant (uninterrupted) and cyclic heating (Fig. 1) at elevated temperature, indicating the ability of the coating to withstand at high temperature, has been shown in Figs. 7 and 8 respectively. The Fig 7 shows that during constant heating at temperatures of (800, 850 and 900°C), the oxidation resistance of modified powder coating is comparatively better than that of the original powder coating, as it is clearly revealed by weight gain per unit area of the both types of powder coatings. This may have happened due to presence of Al in modified powder. During thermal spraying the added Al may have reacted with the Ni present in base powder (EWAC 1005 EC) leading to formation of a high temperature compound, NI_3Al, having oxidation resistance at elevated temperature. In addition to that the Al may have also formed a significantly adhesive, coherent and non porous oxide (Al_2O_3) layer on the coating, which possibly also caused an effective reduction in rate of oxidation of the coating. However, under the cyclic heating of 5, 10 and 15 No. of heating cycles, the weight gain per unit area of the modified powder coating has been found greater than that of the original powder coating as depicted in Fig. 8. This behaviour shows that under cyclic heating conditions the oxidation resistance of the original powder coating is better than that of the modified powder coating, which may be primarily attributed to thermal spalling of modified powder under cyclic heating conditions, unlike its coating remains stable under constant temperature conditions as discussed above. During cyclic heating the cumulative weight gain per unit area of the coating with the increase in number of heating cycle has been shown in Fig. 9. The figure shows that the difference of cumulative weight gain in between the moditied and original powder coatings enhances with the increase in number of heating cycle, which reveals the possible increase in rate of oxidaticn of the modified powder coating at higher cycle of heating, dominated by the spalling action.

CONCLUSIONS

1. Modification of the original powder by aluminium addition changes microstructures of the coating significantly from the presence of cellular structure with a comparatively thicker layer of grain boundary eutectic to a fine co-axial dendritic microstructure with a considerably thinner grain boundary.

2. During heating at constant temperature of 800, 850 and 900°C the oxidation resistance of modified powder coating is better than that of original powder coating.

3. Modification of powder by aluminium addition reduces

hardness of the coating significantly with its practically uniform distribution in the matrix whereas, a large variation in hardness distribution in the coating of the original powder results from the formation of a considerably hard thick layer af eutectic at the grain boundaries.

4. Under cyclic heating, the oxidation resistance of original powder coating is comparatively higher than that of modified powder coating.

5. Both the original and modified powder coatings show practically same wear loss behaviour without achieving a stability after sliding a distance in time beyond 80 minutes at higher normal load of 3.5 kg, but it approaches a stability at lower normal load of 2.5 kg after sliding a similar distance.

6. Increase in normal load considerably enhances the rate of wear.

REFERENCES

1. Gregory E N, Hardfacing, Tribology, Int, Vol.11, (1978)129.
2. Antony K.C. et al. Hardfacing in metal hand book. Welding, Brazing and Soldering, Vol. 6, 9th edition, American Society for Metals, Metal Park Ohio, (1993)'771.
3. Poech M.H. et al. Thermal spraying, PMI, Vol. 25, 5(1993)233.
4. Fontana M G, Corrosion engg, 3rd edition, Mc Graw Hill. International edition, (1987)505.
5. Lugschelder E et al, Thermal spraying, PMI, Vol. 23, (1991)33.
6. Ghosh P K et al. Influence of heat treatment on the properties of wear resistance of tungsten carbide embedded Ni base coating produced by gas thermal spraying ISIJ, Vol.32. 2(1992)250.

ATTENTION MEMBERS

It was decided in the 225th Council Meeting of the Institute held on 9th December, 2000 in Mumbai that :

"..... any member whose subscription due upto 31/03/1996 was outstanding for 3 years as on 31/03/1996 and continues to remain due currently, shall be deleted from the Register of the Institute. This will be an implementation of earlier decision of the Council vide its 197th Meeting held on 17th March, 1995.... ."

– Members may contact IIW Secretariat, if required.

[Following report has been received from Martin Pape, Customer / Product Management, Technical Glass, of SCHOTT DESAG AG, Huttenstr 1, 31073 Grunenplan, Germany]

ATHERMAL Welding Protection Filters are manufactured by Schott Desag and Schott Desag has found a large quantity of fake Eye Protection Products with Athermal printed on the product. Typical characteristics of the fake product are :

Wrong declaration (i.e. Shade 11; Currect Shade is 9) of the shade. According to Din Certco regulation the welder would not be able to identify the right shade for a particular welding process and consequently this will cause eye damage. During an extensive laboratory test by the Company mentioned characteristics were identified. Fake products meet only optical Class 3.

The edges are not fitted properly which could cause injury to the welder's eye.

The fake product (the glass and the plastic foil) has 'Germany' printed on it. According to international Law/ Regulations evry product of German origin has to be marked with "Made in Germany".

[*Editor of the I.W.J. takes no responsibility for the above summarised report.*] — Editor