HOT DIP ALUMINISING OF STEEL WIRE- LABORATORY
SCALE INVESTIGATIONS AND PILOT PLANT STUDIES(*)

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Protective quality of aluminium due to its adherent surface oxide film is well known. In hot-dip aluminising the use is made of this protective nature of aluminium by coating the steel base by dipping it in molten aluminium bath there-by getting an outer aluminium layer and an iron-aluminium layer at the interface. The interfacial alloy layer though possessing good atmospheric corrosion and resistance to oxidation at high temperature is brittle in nature and such must be kept to a minimum of thickness where the end use of aluminised product is for deep drawing, forming etc. Hot-dip aluminium coating on steel base comprising the outer aluminium layer and an alloy layer in the interface should possess both atmospheric and high temperature corrosion resistance.

Various processes have been developed for hot-dip aluminium coating, which differ mainly in the type of flux used to protect the surface of steel prior to entering the molten aluminium bath. In Armco Process (The Sendzimir process) which forms the commercial production basis in U.S.A., a reducing atmosphere of hydrogen or cracked ammonia is used to protect the basis metal. The material enters the aluminium bath under the protective atmosphere and leaves the bath at the other end to be cooled in air. The process involves heavy capital equipment but is capable of producing high quality product.

At present in American practice two types of aluminised sheets by Armco process are made. Type 1 is for heat resistance purposes and is a coating obtained from aluminium bath containing some percentage of silicon whereas in the second type a coating of commercially pure aluminium is given which has good atmospheric corrosion. Silicon helps to keep the interfacial layer of iron-aluminium alloy to a minimum thickness and retards the growth of this alloy when subjected to high temperature for prolonged period.

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Research and development work was undertaken to evolve a hot-dip process which will involve less capital investment and will be simpler in operational technique. Numerous fluxes have been developed and patented in different countries under different trade names. The fluxes used are either molten salt fluxes aqueous fluxes or organic fluxes. National Metallurgical Laboratory has also developed three different processes which differ in the use of the three types of fluxes. The three processes developed have specific applications in different fields. The molten salt flux is suitable for aluminising Post & Telegraph steel wire. The aqueous flux can be used for continuous wire or strip aluminising provided the salt is capable of being removed at 500 to 600°C. The organic flux may suit both the purposes.

Aluminised steel sheet and strip are already in industrial production but aluminising of steel wire is still in the development stage. The first attempt in this direction was made in 1936 and a pilot plant for aluminising of steel wire was installed in 1947 by Alcoa Research Laboratory with the chief aim to develop aluminium coated wire suitable for ACSR Conductors. The National Metallurgical Laboratory has now taken up Pilot Plant project on hot-dip aluminising of steel wire with the object of not only to determine the applicability of research results on a much larger scale but also to solve certain mechanical features. Uniform travel of wire from one end of the cycle to the other without breakage, warping or distortion at optimum speed of feed wire balancing with that of outgoing aluminised steel wire whilst attaining the requisite thickness and uniformity of aluminised coating are some of the mechanical features. On the pilot plant set-up will also be explored possibilities of producing thicker coatings free from interfacial alloy layer for over-head electrical conductors.

Pilot Plant:

Aluminizing has passed the stage of preliminary bench scale laboratory investigation. The process research has now yielded sufficient information for the design of a pilot plant and thus the second field of process that is industrial development is being taken up. The process development interprets the results and laboratory research in terms of a full scale plant. This is possible through a planned programme carried out over a properly designed pilot plant and the results obtained thereby effectively correlated and assessed in terms of economics involved.

The design of the pilot plant is the first step in this direction. The size of the aluminising pilot plant is kept within certain scale-up ratio limits of known engineering practices. Our set-up is almost 1/6 the size of an industrial wire galvanizing unit working at Jamshedpur. This unit is capable of running 5 strands of

wires at a time with varying speeds upto 100 ft. per minute. The plant is a continuous unit comprising feed reel, degreasing in alkaline bath, acid pickling, washing with water at different stages, fluxing in either of the three types of fluxes and finally applying hot-dip aluminium coatings from molten bath of aluminium with or without alloying elements. A vertical exit for air cooling or a quench operation before coiling the wire over the take-up reel constitutes the last operation of the pilot plant.

The coil feeding arrangement has got the advantage that the coil of wire (coil diameter 22 in.) can be placed straight over the feeding arrangement. The feed is slightly tapered and the coil can slide easily over it and rest at the plate fitted at the bottom which is of 26 inches diameter. Brake is provided with a wooden block to keep the wire in tension. The circumference of the feed spool is 5 ft. and our present reduction unit is capable of giving four revolutions per minute, expected to be optimum for aluminising in the present set-up.

The degreasing time in solution of I.C.I. degreaser No.1 is minimum 2 minutes. If a straight bath is taken with wire run of 20 ft. per minute, total length of the bath should be 40 ft. For higher speeds the bath length will have to be increased accordingly. The set-up has the advantage of not only increasing the bath length but also control the rate of travel of the wire through the aluminium bath by coiling any number of turns of wire over the drum rotating over a horizontal axis. The circumference of the drum is about $2\frac{1}{2}$ ft. and hence 8 turns will be initially given to have 20 ft. run of wire per minute. The heating of alkaline degreasing bath is done by means of an immersion electrical heater having thermostatic control, so as to regulate the temperature - 1°C.

The pickling tank is lined with alkathene. Alkathene has got acid resistance upto 70°C towards mineral acids. The length of the bath being 6 ft., total immersion time comes to 18 seconds and this time is optimum for proper pickling avoiding any excessive metal dissolution. The wire proposed to be used in the initial stage will be lead annealed, free from grease etc. and so can be easily pickled. After pickling and washing, the steel wire enters the fluxing bath, which comprises a tank similar to the degreasing tank and contains double boiled linseed oil heated by immersion heater. Provisions are made to employ other fluxes developed at the National Metallurgical Laboratory.

The oiled wire enters the molten aluminium bath. The length of traverse of wire through the bath is about 5 ft. so that the wire remains in contact with metal for about 15 seconds. This period is optimum for the oil to vaporise and the metal coating to take place. The surface of the aluminium bath is cleaned now and then mechanically. The wire emerges from the bath vertically and travels

in air a long way to allow the excess metal to flow down and the wire to cool. The aluminised wire is finally coiled over a coiler. This takeup reel is designed on the basis of the present available reduction unit and so can be easily coupled with it.

Selection of a suitable pot for holding molten aluminium presented difficulties. Refractory lined pots heated electrically by induction or resistance heating have been suggested. One such low frequency induction heated furnace is in use at M/s. Coated Metals Ltd., Bridgend (U.K). This furnace was specially designed by Birlec for aluminising. We had, due to import restrictions, to go for a special alloy cast iron pot which can bear high heating temperature, is shock proof, and at the same time does not react with molten metal. The casting of this pot was done in our laboratory in the foundry using our one ton/hour cupola.

The sinker design for continuous aluminizing for wire was another serious problem because steel or iron gradually dissolves in the molten aluminium. One suitable material suggested is a refractory containing silicon carbide and silicon nitride. This material is not attacked by aluminium and has good wearing properties. In our present setup, we have once again simplified our work by taking special cast iron sinker which is not easily attacked by molten aluminium. The sinker is removable from the bath when the aluminising operation is not taking place.

The furnace design is based on the optimum temperature requirements for hot-dip aluminising. The temperature for aluminising on the other hand depends on the flux used and also to some extent on the composition of the molten metal bath whereas time of contact of the basis metal with the bath determines and controls the intermetallic hard and brittle phase of iron and aluminium and also the outer aluminium layer. This aspect has been studied by one of the authors at BISRA and the results are discussed below.

Experimental Work:

Extensive investigational work was carried out at the Protective Coating Laboratory, BISRA Swansea to explore the possibility of producing thick aluminium coating on steel wire. The object of this investigation was to study the possibility of the replacement of copper wire conductors used at present in India for Telegraph and Telephone communications, by aluminised wire of the same conductivity. The primary desirable feature of such a conductor is the avoidance of the intermediate alloy layer and a thicker outer aluminium layer. A cold wire run was expected to extract the heat of the surrounding metal and thus cause it to solidify on its surface. The arrangement used had the advantage of horizontal movement of wire through the aluminium bath which could be brought above the wire by lowering a

plunger. Molten aluminium floated over molten lead and thus
avoiding a direct contact of the metal with the steel pot base. The
sides of the pot were lined with graphite.

The bath composition and the temperature were kept
fixed and hence the only variable studied was the speed of run
which could be regulated in this case by a D.C. motor attached to
the coiler. The motor had the control to maintain any desired
speed upto 800 f.p.m. The wire remained in tension within the
desired limits by an attachment of spring control at decoiler.
The draw was horizontal and the effect of such a draw was studied.
Tinned wire was used in all experiments. Tin has a low melting
temperature and is also soluble in aluminium. So the pure steel
surface came in contact with molten aluminium bath and the desired
bonding of coating was expected to occur.

The tinned wire used was of 30 thou diameter and the
speed of run was varied which could be recorded by Smith's Speedo-
meter by bringing the knob of the instrument in contact with the
moving part for record of revolutions per minute. The revolutions
could easily be converted to ft.p.m. As the bath size was 6 inches,
with the speed of run 30 ft. per minute the wire had a dipping time
of $\frac{1}{2}$ second only. Higher speed meant less time of contact with the
metal bath. As the wire entered the metal almost cold, half second
and less was not sufficient for the wire to attain the metal temper-
ature and hence some localised freezing round the wire was expected
to take place leading to thick coating. Thicker coatings with
minimum of alloy layer were expected to be produced by increasing
the speed of wire run, but this could not be achieved because a
die was placed just at the exit end of the wire (for control of
thickness and uniformity of coating). The die sheared off the
coating of aluminium and thus the object of thick and uniform
aluminium coating on the wire could not be achieved. The nodulous
coating obtained had a thin alloy layer and an eccentric outer
aluminium layer. Such nodules appearing at many places on the wire
surface make the surface appear very rough. Vertical draw of the
wire and a calm bath may help to produce smoother coatings free from
nodules. The alloy layer in the case of unalloyed aluminium bath in
normal aluminizing is quite thick. The thin layer as observed in
this case is a proof of controlling the development of the alloy
layer by reducing the time of contact of the surface with the molten
metal. The aluminium layer is also thin due to the frozen metal
being sheared at the exit die.

For the same speed, thickness of the wire is the
decisive factor provided other conditions are not changed. A thicker
coating is obtained on a thicker wire as a result of comparatively
greater chilling.

The thickness of the coatings determined metallographi-
cally was further confirmed by analytical methods. The weight of
coating for 30 and 40 thou wires when run at different speeds were
determined by standard stripping test procedures, wherein the alumini-
um could be dissolved in caustic soda solution. The coating weights
for 30 thou wire were 0.15 or 0.21 ozs.per sq.ft. respectively for
speeds of 150-200 ft. or 50-100 ft. per minute, whereas for 40 thou
wire having a speed run of 25-50 ft. per minute the coating weight
was 0.31 ozs./sq.ft. These figures confirm that as the speed is
lower the coating is thicker and as the speed increases the weight of
the coating decreases or the thickness becomes less and less. These
results are contrary to the observations of other workers where a
recommendation has been given for higher speeds to get thicker outer
coatings with thinner alloy layers. This anomaly is due to the
experimental set up in which a horizontal draw through a die has
removed free aluminium layer leaving only the interfacial layer. A
vertical draw on the other hand may yield thicker coatings with
higher speeds and this fact has to be confirmed on the present set up.

Atmospheric Corrosion Resistance of Aluminised Coating:

The resistance to corrosion of any material depends
on its environment. Weaterman reported in 1955 that in an industrial
and highly humid atmosphere, aluminium coatings on wire were substan-
tially superior to equivalent thickness of galvanized coatings. The
coating also showed superiority in marine atmospheres particularly
after 3-4 years of exposure. On the other hand, accelerated corrosion
tests were carried out by Alcoa Research Laboratory for determining
the resistance to corrosion of aluminium coated steel and other
products by intermittent exposure to sodium chloride salt spray. .
These tests showed that though a comparative idea of life can be had,
the result of these tests cannot predict the service life that might
be expected from similar samples exposed to natural environments.
Our work on continuous salt spray test (5% salt by weight) for 120
hours at $36^{\circ}C$ confirmed the superior nature of aluminised coatings.
Further work done on panels aluminised from different baths showed
no bad effect of the presence of titanium upto 0.2% whereas Ni in
amounts 0.1% appeared to reduce the corrosion resistance whereas Mn
in amounts 0.32 per cent improved the corrosion resistance.

As might be expected, because of the protection
afforded to the core wire by the aluminium strands, the resistance to
corrosion of aluminium coated steel wire when employed as core wire
in ACSR is superior to that of the wire exposed to single strands.
This is confirmed by the salt spray test, when aluminium coated steel
wire with a coating of 0.45 oz./sq.ft. shows initial breakdown after
two weeks as single strands, but not until four weeks as core wire
in ACSR.

In general, accelerated tests so far carried out have shown that aluminium coated core steel wire having uniform, continuous sufficiently thick coating provides satisfactory resistance to corrosion which is superior to that of galvanized steel core wire, though it does not approach that of the aluminium based alloy wire. However, even though the performance of the two different types of core wire is improved when employed in ACSR, the aluminium coated steel has an advantage in that the dissimilar metal effect between the zinc coating on the galvanized core wire and the aluminium strands is eliminated i.e. the aluminium coating will not corrode to protect the aluminium strands as with the zinc coating.

The protection given by the aluminium in most atmospheres depends on the undernoted three important characteristics.

(a) The inner Fe-Al alloy layer and the outer aluminium layer must be continuous and reasonably of uniform thickness.

(b) If the aluminium coated steel wire is subjected to fabrication after coating, the cracking and damage to the alloy or aluminium layer must be kept to a minimum.

(c) The ratio of the thickness of the alloy layer to the outer aluminium layer, must favour a thin Al-Fe alloy and a heavy aluminium layer.

The protection due to aluminium is due to (a) Electro-chemical and/or (b) blanket protection. Commercial aluminium has a solution potential of - 0.83 volts when measured in a neutral chloride solution against a 0.1 normal calomel electrode, while steel under similar conditions has a solution potential of - 0.67 volts. Thus under conditions where chlorides are present, a potential difference of 0.16 volts exists between Al and steel. This difference in solution potential varies according to the electrolyte to which the materials are exposed. In some sulphate solutions, there is practically no difference in solution potential between aluminium and steel. Considering these differences in solution potential, it is apparent that the aluminium coating on steel should provide more electrochemical protection in some environments than in others. Such has been found to be the case. In all cases, evidence of atleast electro-chemical protection has been found regardless of the environment to which the aluminium coated steel was exposed.

Aluminium provides electrochemical protection to steel under almost all conditions of exposure. The amount of protection provided to steel by aluminium depends not only on the type of salts present but also on the conductivity of the electrolyte present on the product. Amount of moisture also plays good part in determining the corrosion. In Sea water aluminium provides good corrosion but in places of dampness it is less protective.

Zinc has better solution potential than aluminium and hence it dissolves whereas the aluminium by having less solution potential does not dissolve and thus affords electro-chemical and then blanket protection due to the coring action of the oxide film formed. This leads to better life for aluminium coating. An example of this is the case of core wire for ACSR. Zinc coated wire used as core is eaten away because of its electro-negative nature both to steel and to aluminium. This leads to quick consumption of zinc and exposure of steel wire which has got slight electro-chemical protection for aluminium. Whereas aluminium coated core steel wire does not have this disadvantage in that the aluminium coating and conductor strand are electrochemically neutral.

Resistance to High Temperature:

Aluminium coatings in general and coatings produced from aluminium baths containing silicon possess resistance to heat and thus serve in the conservation of alloying elements in mild steel. Study of this property has been done by several authors and all claim a good resistance to heat for such a product upto $800^{\circ}C$. Dr. Hughes has shown that coatings from aluminium containing silicon resistance to heat upto $700^{\circ}C$. Our work on small strip samples confirms such facts. Aluminium coating showed resistance even at $900^{\circ}C$ whereas Si containing coating showed a poor effect at such high temperature. If the coating can be made more compact probably such a coating might be useful at still higher temperatures.

While studying the effect of various alloying elements to the bath, coatings obtained from such baths were compared for heat resistance properties and it was observed that coatings obtained from baths containing nickel showed superior resistance whereas Ti and Mn slightly impaired the heat resistance.

Future Scope:

The pilot plant, being designed on the lines of other hot-dip processes, will be useful for carrying out research to improve present processes of galvanizing and tinning and to yield quality products.

The work on the pilot plant will be substantiated by the study of the produced product for different applications. Further study will be undertaken in respect of weldability, corrosion at room and at elevated temperatures both in ordinary atmosphere and atmospheres containing humidity or other gases, study of mechanical properties and its improvement, and also development of different kinds of coated wire for different purposes.

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Conclusion:

Experimental study so far done has yielded
sufficient information on the basis of which a pilot plant is being
established at the National Metallurgical Laboratory, which refers
to the aluminizing of steel wire at this stage. The plant will be
useful in the study of the economics of the processes developed
and also in the development of products of specific uses. With the
experience gained in its operation, it is thereafter proposed to
instal a similar installation for the aluminising of steel strips.
It is hoped that data accruing from this pilot plant studies will
assist in over-coming the metallurgical and engineering problems
in the subject of aluminising of steel.

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