Effect of Surface Modification with Aluminium and Copper on the Performance of Stainless Steel 304 Fin

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Abstract: In this present work, experiments were performed on coated Stainless Steel 304 fin to understand the effect of coating on heat transfer parameters of fin. Aluminium and Copper were chosen as coating materials and these were coated on the Stainless steel 304 substrate by using Thermal Spray Method. Conducted experiments on different coated and none coated fins at various heat inputs using Fin-Pin apparatus in our heat transfer laboratory and necessary readings were noted to calculate Reynolds Number, Nusselt Number, Heat transfer coefficient, Thermal conductivity and fin efficiency. The value of thermal conductivity of fin without was obtained as 52.3 W/m K, coated with Aluminium as 166.75 W/m K and coated with Copper as 280.6 W/m K. The improvement of percentage of fin efficiency in case of fin coated with Aluminium was obtained as 73.6% compared with fin without coating, but in case of fin coated with Copper was obtained as 81.7% compared with fin without coating and 4.6% compared with fin coated with Aluminium.

Keywords: Heat flow rate, stainless steel fin, coating, thermal conductivity, Fin efficiency.

1. Introduction
Fins can be used to enhance the performance of heat exchangers with different types of fin profiles. Internal fin can give better option to increase the cooling of electronic systems rather than other methods (Chiang Ko-Ta et al [1]). Position of extended surface, fin shape and cost may play important role to get uniform flow of heat from the system (B. Moshfegh et al. [2]). Rectangular geometry of fin was best suitable profile to get more heat transfer among various geometrical shapes due to its simple construction, easy manufacturing and low cost. Generally two fin configurations like horizontally based vertical fins and vertically based vertical fins are used in various applications. Though, horizontal orientation was not recommended due to its low quantity of heat transfer from the system (Welling J. R. et al.[3] ). Enhance the heat flow with fins were most suitable method because of its easy construction, most economical and convenient. Fins can be used to increase the heat flow by increase the surface area to heat flow to obtain required rate of heat transfer from the system. It is required to maintain minimum the gap between fins and base material surface as to restrict to fall of the heat transfer using fins even if surface area increases with number of fins. Fins may also create narrow the flow passage and afford boundary layer interferences which may result on the performance of heat transfer from the system (F. Harahap et al. [4]). Improving surface area with fin is most suitable due to its less weight, less space occupancy and most economical. Extended surfaces were used in automobiles and various engineering applications to achieve required heat flow (D.Q. Kern et al. [5]). It was noticed that more heat transfer was obtained using nano fluids compared to other fluids. Study the nano fluid properties like as viscosity, thermal conductivity and specific volume during the 2000. (Sadik Kacak et al. [6]). It was noticed in his experimental work, volume fraction (0.003 % by volume)
of copper oxide (CuO) nano particles were mixed with de-ionized water dispersed to form nano fluid. He studied the performance of convective heat transfer at the steady state by passing nano fluid through a copper tube and concluded that achieve better results compared to conventional fluids (Asirvatham et al. [7]). Studied the performance of shell and tube heat exchangers with Segmental type and Disc-Doughnut Type Baffles and it was concluded that heat exchangers with Disc-Doughnut Type Baffles transfers more heat compared to Segmental type baffles (V.Sreedhar et al. [8]). Brass is coated on Stainless steel using Laser Engineered Net Shaping (LENS) technique to analyze thermal conductivity of Stainless Steel. They observed that at temperature of 100°C, coated Stainless Steel shows better improvement in thermal conductivity which was increased by 65% and low thermal resistance was observed between coating material and substrate by reduce the dilution with defect free sound interface. They observed that best future based thermal coating can develop with metal matrix composites which should have low thermal expansion to improve the heat flow characteristics by using laser processing (Felix A. Espana et al [9]). They conducted experiments on substrate coated with nano materials coated and suggested the importance of nano material coating on the parent material become futuristic parameter in the field of thermal applications (Prabhu et al. [10]). If fluid velocity increases, then heat transfer co-efficient also increases and vice versa. However pump takes more power as to supply fluid with high velocity. To obtain required heat transfer flow with enhancing the heat transfer coefficient is not better option by increasing the fluid velocity. In other way, rate of heat flow can be increased by reducing the sink temperature and it was practically impossible to decrease sink temperature. Finally, rate of heat flow between the fluids can be improved by increasing the surface area in case of convective heat transfer which was achieved by adding fin (extended surface) to the base material. The performance of fin can be improved by using surface modification with high thermal conductivity materials on the substrate (Prabhu et al. [11]). Caron nano tubes were coated on Aluminium fins with the help of PVD method to analyze the performance of fin and examined the other flow characteristics between with and without coated Aluminium fin. It was observed that efficiency of fin was improved by 5% with coated Aluminium fin than without coated Aluminium fins (R. Senthilkumar et al. [12]). Stainless steel fin was made in elliptical shape and coated with multi walled carbon nano tubes. They were conducted experiments on with and without coated fin at different surface temperatures to study the effect of coating on the substrate. Estimated the various heat flow parameters like temperature distribution, thermal conductivity, heat transfer coefficient, efficiency of fin, shaped tube efficiency at various heat inputs and studied the results with coated and non coated Stainless Steel fin. It was obtained from the results that thermal conductivity of coated Stainless Steel fin was increased by 21.1% compared with non coated Stainless Steel because of decrease in surface temperature. Also the convective heat transfer coefficient of coated Stainless steel fin was improved by 7% compared to without coated Stainless Steel fin. The shaped tube efficiency of coated Stainless Steel was enhanced by 6.2% compared to without coated Stainless Steel fin. The fin effectiveness of coated Stainless Steel fin was increased by 21.8% compared to without coated Stainless Steel fin (J.Nagarani et al. [13]). Brass and Aluminium were chosen as coating materials and stainless steel fin was selected as substrate. Fin was coated with 250 micron of thickness by using Twin wire coating technique and conducted experiments on with and without coated fin at different heat inputs to analyze the effect of coating on the performance of fin. It was noted that Nusselt number of S.S coated with Aluminium was improved by 1.36% compared to coated with Brass and 2.1% compared to without coated fin and there was rise in efficiency of fin coated with Brass and Aluminium materials by 14-73% compared to without coated fin (Sreedhar Vulloju et.al [14]).

Form the above information, it was concluded that coating can effect the rate of heat transfer through the substrate. We chosen stainless steel 304 fin as substrate and it was coated with Aluminium and Copper using thermal spray coating method. We conducted experiments on coated and non coated fin using pin fin apparatus at different surface temperatures to study the influence of coating on the performance of fin.
2. Substrate and Coating Materials
Generally coating is applied on the surface of substrate to protect from corrosion and increasing lifetime but here the coating on substrate can also to boost heat transfer characteristics. Coating method is used for either in permitting or diathermic of heat flow based on its application. Thermal Barrier Coatings are coating material which not allows the heat transfer from or into a system. High thermal conductivity materials are selected as coating materials causes to improve the heat flow performance of the systems. In our work Stainless steel 304 is considered as substrate. Aluminium and Copper are chosen as coating materials of 250 micron thickness. The coating material wires and different coated fins were shown in fig. 1 and fig. 2.

![Coating Material Wire](image1)

![Coated Stainless Steel](image2)

3. Microstructure of Coated Fin
The coating was provided on the stainless steel fin with Aluminium and Copper with thickness of 250 microns using twin wire coating method. After the coating process, the specimens were dried individually for 3-6 days depends on thickness of coating on the substrate. It is required to know the bonding of coating material on stainless steel fin as to examine the effect of coating on the performance of fin. If coating is done on the substrate without any defects so that heat loss can be decreases through the coating surfaces. The microstructure of coated fin was observed through the microscope integrated with computer and its image had been taken as shown in the fig 3 & 4.

3.1 Stainless Steel coated with Aluminium

**Etchant Used:** Polished

**Observation:** Microstructure shows (fig 3.) finely distributed intermetallic particles on the substrate meanwhile some porosities on coating were observed. No bonding defects were observed. Surface of coating material on substrate was appeared as smoothly and no cracks were noted. This information implied that Aluminium was coated on substrate properly using thermal spray coating method. Air is occupied in the porosities which may leads to decline the heat flow from the fin to surroundings. (Porosities- It is a void space on a material by formation of holes)

![Microstructure of Stainless Steel coated with Aluminium](image3)

3.2 Stainless Steel coated with Copper

**Etchant Used:** Polished

**Observation:** Microstructure shows (fig 4) coating particles were completely bonding with the base metal. Little porosities observed on the coating were observed. No bonding defects were observed.
Surface of coating material on substrate was appeared as smoothly and no cracks were noted. Thickness of coating material of 250 microns over the entire surface of stainless steel fin was maintained as uniformly and no uneven coating surfaces on the substrate were observed. This information implied that Copper was coated on base material properly using thermal spray coating method. It was noted that formation of porosities in Copper coating is somewhat less compared to Aluminium coating.

4. Thermal Analysis

Pin Fin Apparatus in our heat transfer laboratory was used to conduct experiments on coated fin at different heat inputs as shown in the Fig.5. It consists of duct, test section, blower, measuring flow meter, thermocouples and control panel. Blower is used to supply the air through the duct. Discharge of air through the duct was measured by Orifice meter. Dimmer stat was arranged on control panel which was used to supply the required voltage to the fin surface. Voltmeter, Ammeter and Digital temperature indicator were used to measure voltage, current and temperature respectively.

Table 1. Specifications of fin and test setup:

| Specification                        | Value                      |
|--------------------------------------|----------------------------|
| Diameter of Fin                      | 14.3 mm                    |
| Blower capacity                      | 0.24 HP, 2800 rpm, 180 watts |
| Length of fin                        | 180 mm                     |
| Dimensions of Duct                   | 150 mm x 100 mm x 700 mm   |
| Diameter of Orifice                  | 14 mm                      |
| Range of Temperature Indicator       | 0-100°C                    |
| Range of Voltmeter                   | 0-230 V                    |
| Range of Ammeter                     | 0-2 Amp                     |
| Coefficient of discharge C_d         | 0.64                       |
| Dimmer stat                          | Open type, wire wound      |

Five holes were drilled at equal distance on Stainless Steel Fin as to attach thermocouples to measure average surface temperature of fin \( (t_a) \) as shown in fig.

Average Surface Temperature \( t_a = \frac{(t_1+t_2+t_3+t_4+t_5)}{5} \)
Here, $t_1 \degree C$ is the surface temperature of fin at hole1 and similarly $t_2$, $t_3$, $t_4$ and $t_5$ are the surface temperature of fin at holes 2, 3, 4 and 5 respectively as shown in fig 6. $T_a$ is required to calculate mean film temperature of air ($T_{mf}$).

Mean film temperature of air is obtained is expressed in the equation (2)

$$T_{mf} = t_a + t_d$$  \hspace{1cm} (2)

Where, Duct temperature ($t_d$) which is measured with thermocouple arranged inside the duct. The required properties of air are obtained based on the value of $T_{mf}$.

Velocity of air at orifice ($V_0$) is obtained is expressed in the equation (3)

$$V_0 = \frac{C_d V}{\sqrt{\rho w}} \hspace{1cm} \text{m/s}$$  \hspace{1cm} (3)

Where, $g$= acceleration due to gravity = 9.81 m/s$^2$, $h$= Manometer reading in m, $\rho_w$= density of water = 1000 kg/ m$^3$, $\rho_a$= density of air kg/m$^3$, $C_d$ = 0.64 orifice meter coefficient

Velocity of air through the duct ($V_d$) is calculated from the continuity equation and it is expressed by an equation (4)

$$V_d = \frac{V_0 \pi \times d_0^2}{w \times b} \hspace{1cm} \text{m/sec}$$  \hspace{1cm} (4)

Where, $d_0$ = diameter of the orifice in m, $w$ = width of duct in m, $b$ = breadth of duct in m

Reynold’s Number ($Re$) is given by equation (5)

$$Re = \frac{VD}{\nu}$$  \hspace{1cm} (5)

Where, $D$=Diameter of the Fin in m, $V$ = Velocity of air through duct in m/s, $\nu$ = kinematic viscosity of the air at $T_{mf}$

Nusselt Number [Nu] is expressed by an equation (6) (Sreedhar Vulloju et.al [19])

$$\text{Nusselt Number: } Nu = 0.683(Re)^{0.466} \times Pr^{0.333} \quad 40<Re<4000$$  \hspace{1cm} (6)

Heat Transfer Coefficient of air ($h$) is calculated by an expression (7)

$$\text{Heat Transfer Coefficient (h) } = \frac{(Nu \times K_{air})}{D} \hspace{1cm} (7)$$

Where, $K_{air}$ =Thermal conductivity of air at $T_{mf}$, Fin parameter [m] as given in equation (8)

$$m = \frac{hp}{\sqrt{(KA)}} \hspace{1cm} (8)$$

Here, $P$ = perimeter of the fin m, $A$ = Cross sectional area of Fin m$^2$, $K$ = Thermal conductivity of Fin material

Efficiency of Fin ($\eta$) is expressed by an equation (9)

$$\eta = \frac{\tan (md)}{mL} \hspace{1cm} (9)$$

Where, $L$= Length of the Fin in m

5. Results and Discussions

Experiments were conducted at steady state conditions on coated and none coated fin using Pin Fin equipment at various voltage ranges between 50 to 75 watts shown in fig.6 and noted necessary
readings to estimate heat flow parameters like Reynolds number, Nusselt number, Thermal conductivity, Heat transfer co-efficient and fin efficiency.

Table 2. Result parameters of Fin Material

| Fin Material          | Reynolds Number | Nusselt Number | Heat Transfer Coefficient (W/m²K) | Thermal Conductivity (W/m K) | Fin Parameter (m) | Efficiency (%) |
|-----------------------|-----------------|----------------|-----------------------------------|----------------------------|-------------------|----------------|
| Stainless Steel       | 164.87          | 6.55           | 12.015                            | 52.3                       | 10.96             | 50.4           |
| S.S Coated With Al    | 176.19          | 6.69           | 12.1                              | 166.75                     | 4.42              | 87.5           |
| S.S Coated With Cu    | 182.82          | 6.86           | 12.81                             | 280.6                      | 3.51              | 91.6           |

Reynolds Number shows an important parameter in the flow of heat transfer rate as its value increases which causes to improve Nusselt Number as well as Heat transfer through the fin. The value of Reynolds Number of Stainless Steel 304 without coating was obtained as 164.87, coated fin with Aluminium as 176.19 and coated fin with Copper as 182.82. It was pointed out that coating can effect on the value of Reynolds Number as shown in fig 7 and it increases the Reynolds number in different way with different coating materials. It was noted that Reynolds Number of Copper coated fin was more than other two cases. The value of Reynolds Number of Fin coated with Aluminium was found as 6.8% more than the fin without coating but in case of fin coated with Cu, it was obtained as 10.8% more than the fin without coating.

Nusselt Number in fin without coating was found as 6.55, coated with Aluminium as 6.69 and coated with Copper as 6.86. From these results, it was observed that coating can effect the value of Nusselt Number and Copper coated fin has the Nusselt Number more compared with Aluminium coated fin and fin without coating as shown in fig 8. It was noted that coating on the substrate can increase Nusselt Number. Heat transfer co-efficient (h) plays a important role in the convection mode of heat transfer through the fin. It was calculated for different types of fins by an expression given in equation (7). The value of heat transfer co-efficient in case of fin without coating was found as 12.015 W/m²K, coated with Aluminium as 12.1 W/m² K and coated with Copper as 12.81 W/m² K. It was noted that Coating
can effect the value of heat transfer co-efficient and its value was obtained more in fin coated with Copper compared with other two cases as shown in fig 8.

Thermal conductivity (K) is the property of material which influences the flow of heat transfer through the conduction mode and it was determined for different types of fin with the principle of Fourier equation. The value of thermal conductivity of fin without was obtained as 52.3 W/m K, coated with Aluminium as 166.75 W/mK and coated with Copper as 280.6 W/mK as shown in table 2. We noted that coating can influence the value of thermal conductivity of fin and its value may vary with respective to thermal conductivity of coating material as if coating material has more thermal conductivity causing to increasing the value of thermal conductivity of substrate and vice versa as shown in fig 9. So that we found that fin coated with Copper was obtained as high value of thermal conductivity compared to fin coated with Aluminium. It was examined that the value of thermal conductivity of fin coated with Aluminium was found as 3.18 times more than the fin without coating, but in case of fin coated with Copper was given as 5.36 times more than the fin without coating and 1.68 times more than the fin coated with Aluminium. Fin parameter (m) was calculated using an equation 8 and its value was utilized in the determination of fin efficiency as equation of fin efficiency is the function of fin parameter given by expression(9). We noted that the value of fin parameter of fin without coating as 10.96, coated with Aluminium as 4.42 and coated with Copper as 3.51as shown in the table 2. The less value was noted in fin coated with Copper compared to other cases. So that coating with high thermal conducting can decrease the value of fin parameter and vice versa. From the result table 2, we observed that fin efficiency of fin without coating as 50.4%, fin coated with Aluminium as 87.5% and fin coated with Copper as 91.6% and the coating can effect the fin efficiency as shown in fig 10. It shows that the value of fin parameter of fin coated with Copper has less and it has more efficiency corresponding to Al coated fin and none coated fin. The improvement of percentage of fin efficiency in case of fin coated with Aluminium was obtained as 73.6% compared to fin without coating, but in case of fin coated with fin coated with Copper was obtained as 81.7% compared with fin without coating and 4.6% compared with fin coated with Aluminium.

6. Conclusions
Experiments were conducted on coated and none coated Stainless Steel 304 using Pin Fin Apparatus at various heat inputs as to understand the effect of coating on heat flow characteristics of fin. From experimental results, it was noted that fin coated with Aluminium and Copper has effective performance than the fin without coating. It was concluded that the coating on fin can improve the thermal conductivity of fin material rather than heat transfer coefficient even increase little surface area so that heat dissipation from the fin through the mode of conduction is more compared with convection heat transfer. Surface area of coating material on substrate was not influence more on heat transfer as
thickness of coating was very small (250 microns). The coating layer on the surface of fin absorbs heat passing through the fin material and transfer to surrounding. Porosities were formed on surface of fin during the coating process but air fills in the porosities which leads to decrease the heat transfer through the fin. Copper was coated on stainless steel 304 fin more effectively so that less porosities were observed in copper coated fin compared to Aluminium coated fin. So fin coated with Copper shows better performance results compared to fin coated with Aluminium.

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