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Experimental Analysis of Heat Transfer Rate by Applying Ceramic Coating on Metal Surface

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ABSTRACT

In this project we have study the heat transfer analysis of ceramic coating applied on stainless steel metal surface. The experiment is carried out emissivity test rig. The coating technique is used by Plasma Electrolysis Oxidation (PEO). The result has been compared to the pure stainless steel and ceramic coated stainless steel with reference of the black body.

KEYWORDS: stainless steel,ceramic coating, Plasma electrolysis oxidations,heat transfer rate, Emissivity.

1. INTRODUCTION

Energy is a core subject to education in Mechanical Engineering (ME). Among the various issues, technologies for energy recovery and conversion are at the forefront of any mechanical engineering curricula.

1.1 Heat

Heat is the amount of energy that flows spontaneously from a warmer object to a cooler one. More generally, heat arises from many microscopic-scale changes to the objects, and can be defined as the amount of transferred energy excluding both macroscopic work and transfer of part of the object itself. The process of heat, also called heating

1.2 Heat transfer

Heat transfer is a discipline of thermal engineering that concerns the generation, use conversion, and exchange of thermal energy (heat) between physical systems. Heat transfer is classified into various mechanisms, such as thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes. Engineers also consider the transfer of mass of differing chemical species, either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the samesystem.Heat conduction, also called diffusion, is the direct microscopic exchange of kinetic energy of particles through the boundary between two systems. When an object is at a different temperature from another body or its surroundings, heats flows so that the body and the surroundings reach the same temperature, at which point they are in thermal equilibrium. Such spontaneousheattransferalwaysoccursfromaregionof hightemperaturetoanotherregionoflower temperature, as described by the second law ofthermodynamics.Heat convection occurs when bulk flow of a fluid (gas or liquid) carries heat along with the flow of matter in the fluid. The flow of fluid may be forced by external processes, or sometimes (in gravitational fields) by buoyancy forces caused when thermal energy expands the fluid (for example in a fire plume), thus influencing its own transfer. The latter process is often called "natural convection". All convective processes also move heat partly by diffusion, as well. Another form of convectionisforcedconvection. Inthiscase thefluidisforcedtoflowbyuseof apump,fanorother mechanicalmeans

1.2.1 Modes of Heat Transfer

Conduction

Conduction occurs when two object at different temperatures are in contact with each other. Heat flowsfromthewarmertothecoolerobjectuntiltheyarebo th atthesametemperature.Conductionis the movement of heat through a substance by the collision of molecules. At the place where the two object touch, the faster-moving molecules of the warmer object collide with the slower moving molecules of the cooler object. As they collide, the faster molecules give up some of their energy to the slower molecules. The slower molecules gain more thermal energy and collide with other molecules in the cooler object. This process continues until heat energy from the warmer object spreads throughout the cooler object. Some substances conduct heat more easily than others. Solids are better conductor than liquids and liquids are better conductor than gases. Metals are very good conductors of heat, while air is very poor conductor of heat. You experience heat transfer by conduction whenever you touch something that is hotter or colder than your skin e.g., when youwash your hands in warm or coldwater.In liquids and gases, convection is usually the most efficient way to transfer heat. Convection occurs when warmer areas of a liquid or gas rise to cooler areas in the liquid or gas. As this happens, cooler liquid or gas takes the place of the warmer areas which have risen higher. This cycle results in a continuous circulation pattern and heat is transferred to cooler areas. You see convection when you boil water in a pan. The bubbles of water that rise are the hotter parts of the water rising to the cooler areaofwaterat thetopofthepan.Youhaveprobablyheardtheexpressio n"Hotairrises andcoolair falls to take its place" - this is a description of convection in our atmosphere. Heat energy is transferred by the circulation of theair.

Radiation

Bothconductionandconvectionrequiremattertotransfe rheat.Radiationisamethodofheattransfer that does not rely upon any contact between the heat source and the heated object. For example, we feel heat from the sun even though we are not touching it. Heat can be transmitted thoughemptyspace by thermal radiation. Thermal radiation (often called infrared radiation) is a type electromagnetic radiation (or light). Radiation is a form of energy transport consisting of electromagnetic waves travelling at the speed of light. No mass is exchanged and no medium is required.Objects emit radiation when high energy electrons in a higher atomic level fall down to lowerenergy levels. The energy lost is emitted as light or electromagnetic radiation. Energy that is absorbed by an atom causes its electrons to "jump" up to higher energy levels. All objects absorb and emit radiation. (Here is a java applet showing how an atom absorbs and emits radiation) When the absorption of energy balances the emission of energy, the temperature of an object stays constant. If the absorption of energy is greater than the emission of energy, the temperature of an object rises. If the absorption ofenergyislessthantheemissionofenergy,thetemperat ureofanobjectfalls.Thermal radiation is the emission of electromagnetic waves from all matter that has a temperature greater than absolute zero. Thermal radiation reflects the conversion of thermal energy into electromagnetic energy. Thermal energy is the kinetic energy of random movements of atoms and molecules in matter. All matter with a nonzero temperature is composed of particles with kinetic energy. These atoms and molecules are composed of charged particles, i.e., protons and electrons. The kinetic interactions among matter particles result in charge acceleration and dipole oscillation. This results in the electrodynamic generation of coupled electric and magnetic fields, resulting in the emission of photons, radiating energy away from the body. Electromagnetic radiation, including visible light, will propagate indefinitely in vacuum.The characteristics of thermal radiation depend on various properties of the surface from which it is emanating, including its temperature, its spectral emissivity, as expressed by Kirchhoff's law. The radiation is not monochromatic, i.e., it does not consist of only a single frequency, but comprises a continuous spectrum of photon energies, its characteristic spectrum. If the radiating body and its surface are in thermodynamic equilibrium and the surface has perfect absorptivity at all wavelengths, it is characterized as a black body. A black body is also a perfect emitter. The radiation of such perfect emitters is called black-body radiation. The ratio of any body's emission relative to that of a black body is the body's emissivity, so that a black body has an emissivity of unity (i.e., one).

OBJECTIVES

- Understanding the process of emissivity on different surfaces
- Determination of heat transfer rate on different surfaces
- Comparing the results of heat transfer rate on black body and stainless steel,ceramic coated surfaces
- Determination of better surface for to store the heat

DESCRIPTION OF COMPONENTS

- Stainless Steel Plate (Grey Body)
- Black Body
- Ceramic Coated Plate
- Heater
- Thermocouples and Digital Temperature Indicator
- Voltage Regulator and Digital Indicator
- Current Flow Digital Indicator
- Main Switch

Emissivity test rig

2. METHODOLOGY

Emissivity

Any hot body maintained by a constant heat source, loses heat to surroundings by conduction, convection and radiation. If two bodies made of same geometry are heated under identical conditions, the heat loss by conduction and convection can be assumed same for both the bodies, when the difference in temperatures between these two bodies is not high. In such a case, when one body is black & the other body is gray from the values of different surface temperatures of the two bodies maintained by a constant power source emissivity can be calculated. The heat loss by radiation depends on:

a) Characteristic of the material
b) Geometry of the surface and
c) Temperature of the surface

The heat loss by radiation when one body is completely enclosed by the other body is given by

$$Q = \left[\frac{\sigma A_1 (T^4_1 - T^4_2)}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_2}\left[\frac{1}{\varepsilon_2} - 1\right]} \right]$$

If a body is losing heat to the surrounding atmosphere, then the area of atmosphere A_2>> area of body A_1. Thus if any body is loosing heat by radiation to the surrounding atmosphere equation (1) takes the form.

$$Q = \sigma A_1 \varepsilon (T^4_1 - T^4_2)$$

Where, σ = Stefan Boltzmann constant = 5.6697×10^{-8} W/m² K⁴

A_1 = Surface area in m²

ε = Emissivity

T_1 = surface temperature of the body in K and

T_2 = surrounding atmospheric temperature in K

Let us consider a SS Plate with Ceramic Coated & a SS Plate with identical geometry being heated under identical conditions, assuming conduction & convection heat loss to remain the same. Let Q_C and Q_S be the heat supplied to SS Plate with Ceramic Coated & a SS Plate bodies respectively.

If heat input to both the bodies are same,

$Q_C = Q_S$

Assuming, heat loss by conduction and convection from both bodies to remain same.

Heat loss by radiation by the Ceramic Body = heat loss by radiation by the SS Body

$$\sigma \times A_C \times \varepsilon_C \times (T^4_C - T^4_{CA}) = \sigma \times A_S \times \varepsilon_S \times (T^4_S - T^4_{SA})$$

As geometry of two bodies are identical,

$A = A_S = A_C$ and $\varepsilon_C = 1$

Therefore,

$$\varepsilon_C = \frac{(T^4_S - T^4_{SA})}{(T^4_C - T^4_{CA})}$$

Where,

Suffix 'C' stands for Ceramic Body

Suffix 'S' stands for SS Body

Suffix 'CA' stands for Ceramic ambient.

Suffix 'SA' stands for SS ambient.

Apparatus

The setup consists of a 130mm dia of two plates i.e. (Stainless steel plates, ceramic coated plate) one surface blackened to get the effect of the black body and other is tested material placed on above the heater to give the effect of the gray body. Both the plates with mica heaters are mounted on the ceramic base covered with chalk powder for maximum heat transfer. Three Thermocouples are mounted on their surfaces to measure the temperatures of the surface and one more to measure the enclosure/ambient temperature. This complete arrangement is fixed in a closed chamber for visualization. Temperatures are indicated on the digital temperature indicator with channel selector to select the temperature point. Heater regulators are provided to control and monitor the heat input to the system with voltmeter and ammeter for direct measurement of the heat inputs. The heater controller is made of complete aluminium body having fuse.

Experiment Procedure

1. Switch on the Mains.
2. Operate the Heater Controller dimmer very slowly and give same power input to both the heaters Say Point 1 or 2 or 3 …….
3. Note down the temperatures for every 10min, from T5 to T8 by rotating the temperature selection switch.
4. Repeat the experiment for different heat inputs.
5. Note down the values of input Voltage, Current and Temperature according to shown in digital output.

3. RESULT AND DISCUSSION

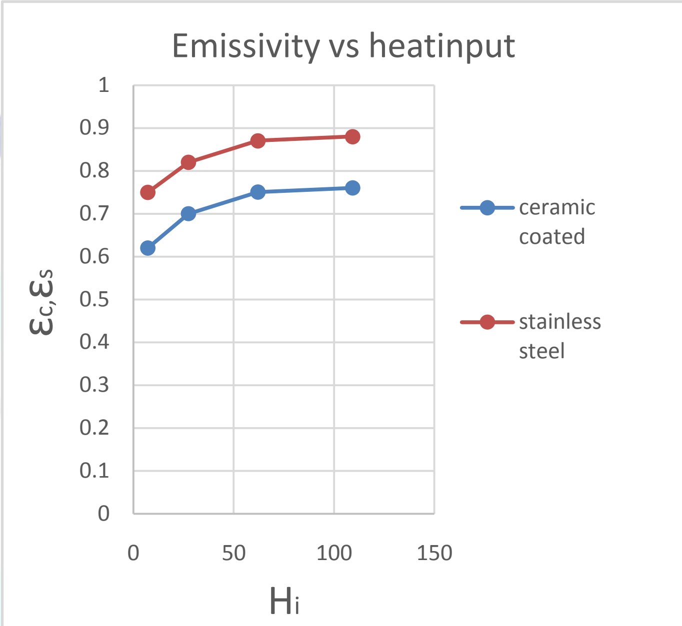

Figure 1

The final result of ceramic aluminium oxide coating on stainless steel and stainless steel is on figure 1. The figure show on the when gradual increase of heat input and change in time the change in emissivity can be seen in above figure1.

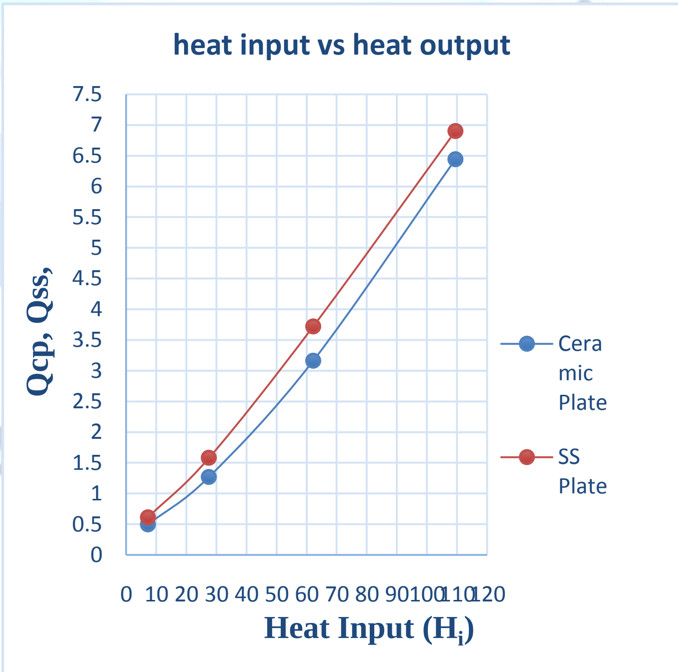

Figure 2

The final result of ceramic aluminium oxide coating on stainless steel and stainless steel is on figure 2. The figure show on the when gradual increase of heat input and change in heat output can be seen in above figure2

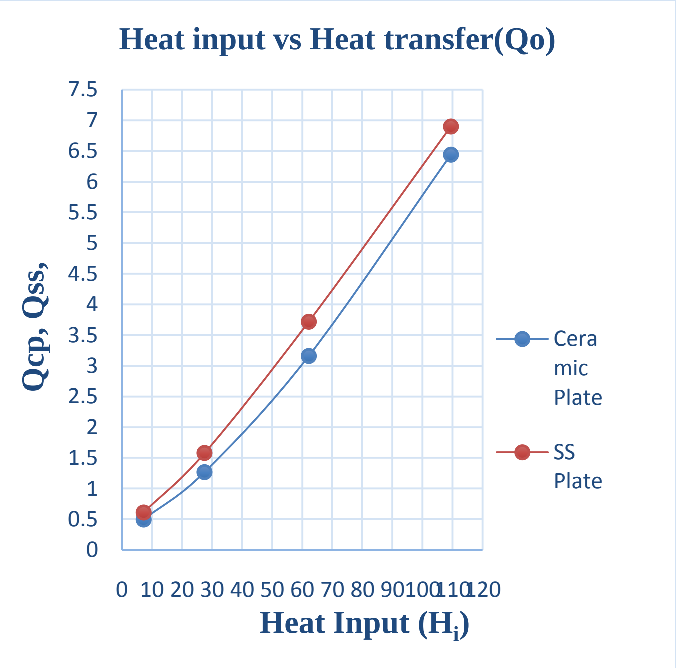

Figure 3

The final result of ceramic aluminium oxide coating on stainless steel and stainless steel is on figure 3. The figure show on the when gradualincrease of heat input and the change in heat output can be seen in above figure3.

4. CONCLUSION

We successfully concluded that when compared to Ceramic Coated Aluminium Oxide on Stainless Steel plate and without coated Stainless Steel plate, the result of rate of Heat Transfer Rate and also Emissivity is low while applying 10 Microns of coating, so when we increase the thickness of ceramic coating there is much chances of getting a better result. The lower Emissivity value comparison indicates that, there is store of heat in the ceramic plate, the emission of heat is high in non-coated plate (SS). The storing of heat energy present inside body this makes to improve the efficiency of the system, when there is a need of reduce heat loss like automobile engines, exhaust manifolds, headers, Boiler, Turbo Charger, Microwave ovens etc, it makes the useful, it's not only increases the Efficiency but also acts for protecting automobile parts from degradation of material composition due to friction that occurs during parts movement. Ceramic coatings doesn't stick to the surface of the metal like paint; the ceramic coating bonds with the material of the parts. Due to this, it's a tough coating and doesn't flake easily.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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