Thermovision study on Alumina’s Ra v/s Ts for AIDHVACS to control COVID-19

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Abstract. The current study is the authors’ next work from the thermo vision perspective of real time single sun solar field performance infrared thermography (IRT) on commercial grade Alumina solar absorber surface coatings (SASCs) to recognize surface roughness (Ra) as one of the important production process parameters. In a previous study, it was investigated with IRT, and found that Ra<1.8 is favorable and hard anodized Alumina (HAAO) coatings exhibits better surface temperature (Ts) gain as compared to organic dyed non-HAAO coatings on Aluminum substrate, and are more stable in solar field for many years in open air environment without degrading their performance. It may be useful in better optimization of SASCs specifically for personal protective equipments (PPEs) sanitization and artificial intelligence (AI) driven heating ventilation air conditioning (HVAC) systems (AIDHVACS) design to control Covid-19 in current situations. The influence of Ra of few microns ~ <15 µm on Alumina SASCs’ Ts gain is examined. The presented study shows that more than 1.05 mm thickness of substrate flat is necessary to develop good quality of alumina coating; Ra<1.8 µm is favorably expected to the extent of Ra value approaching as close as to nanoscale ~ 5-500 nm; local surface temperature gained is depending upon local Ra profile as well as upon surface morphology in addition to the anodizing process parameters and other environmental factors. It suggests that the optimal surface profile should be designed as an integral to the production line processes. The substrate surface chemical composition may also change while processing due to surface contact with the processing tools, which may also result in altered solar field performance due to substrate altered material composition prior to hard anodizing process, as examined with X-ray fluorescence spectrometry (XRF) and ultraviolet–visible spectrophotometry (UV-VIS). The novelty is that other studies of surface roughness parameter is focused upon convective heat transfer inside tunnel or duct solar heat absorbers e.g. air heaters, whereas the authors have focused upon surface roughness of solar radiation receiving outer surface as an important commercial production process variable having effect upon conductive heat transfer in solar thermal power systems. The AIDHVACS needs machine learning and big data analysis as the need of the hour.

Index Terms—Selectivity, Alumina HAAO, Surface Roughness Ra, nanoporous coatings, COVID-19
1. Introduction

The Pandemic of COVID-19 has emerged new challenges[1] of social distancing, power or energy resourcing, AI driven HVAC systems design, power or energy sale/purchase pricing, eco-friendly sustainable power and power system efficiency in the field of thermal power generating systems (TPGSs) as well as new opportunities in various research and development projects for developing the commercial scaled volumetric receiver technology since the early 1990s [2] to further explore the applications of SASCs[3-5]. Power system efficiency increases with the working thermodynamic cycle temperature but the overall safety gets compromised hence conventional atomic or coal thermal power plants may be getting less preferred by the public concerns due to higher costs to the society in view of the environment impact analyses[1] as well as COVID-19. Pandemic induced public health concerns of the power plant manpower due to social distancing and need of sanitization of PPEs very frequently e.g., Switchgear operators used to wear shared PPEs, Boiler Ash Handlers also used to wear shared PPEs etc., they now need to wear separate personalised PPEs, that too are required to undergo frequent sanitization cycles for reuse and prolonged uses.

Solar energy absorber can serve this need of frequent sanitization of PPEs, one of them is HAAO surface or alumina solar paints which gains sufficiently high temperature on its coating surface in single or multi-sun to sanitize PPEs through air heaters or steam generators near to 100 °C or even more, but whether or not the artificial or production process induced surface roughness $R_s$ of the heat collecting surface substrate affects the solar receiver's maximum surface temperature is still remaining a field of detailed research. Authors observed that hard anodised alumina flat surfaces respond sensitively to study surface roughness impact upon surface temperature gain through IRT even under single sun in real field conditions, the study may be useful for development of commercial grade SASCs, and hence present study is limited to this approach of HAAO as specimens. The present study may be further extended using various other SASCs.

In authors’ earlier work HAAO SASCs were tested with the help of an infrared (IR) thermometer, on 3.15mm Aluminum substrate [3][4] which cannot capture the total solar field view of the HAAO SASCs performance at a moment, hence comparison among various HAAOs developed in real time solar field application is better suggested through Thermography camera (TGC) [5]. Therefore the present experiment of comparative study of HAAO SASCs is done using TGC.

$R_s$ < 1.8 μm may enhance the SASC performance in the solar field as found in the present study, agreeing with others and authors previous similar studies [3-10].

2. Alumina Specimens’ Commercial Grade Development Process

Self-ordered Anodized Alumina (AAO) may be developed by mild anodization (MA) within limits of voltage, electrolyte etc. as processing parameters [11–15]. The self-ordering regime limits accessible interpore distances and pore diameters. But, MA requires several days of processing time to obtain commercially suitable AAO due to low current density < 15 mA cm$^{-2}$ and oxide growth rates ~ 2–6 μm h$^{-1}$ [16]; the time factor makes mild anodization process not favorable for mass production i.e. commercial development of SASCs in competitive market.

Therefore hard anodization process [16–19] for fast fabrication of highly self-ordered HAAO with a wide range of pore sizes and interpore distances is found suitable for practical commercial grade SASC development. An excellent array of nanopores is obtained in HAAO in a controllable procedure by applying a high current density (400–800 mA cm$^{-2}$) and oxide growth rates (50–100 μm h$^{-1}$) for a relatively short time (~1 h). This needs the process temperature control and thicker substrate of Aluminum alloys > 1.05mm as one of the specimen developed in present study got broken due to its low thickness of 0.71mm. HAAO’s High growth rate is 25–30 times higher than Mild-AAO which is an important factor in the use of HAAO for various industrial and commercial applications.

Oxalic-acid-based anodization process for long-range ordered HAAO membranes has been widely used in industry for high-speed fabrication of mechanically robust, very thick (>100 μm) and low-porosity alumina films since the 1960s [17]. In present work, It is found that solar field performance of oxalic-acid-mixed HAAO coating is better than only sulphuric acid based HAAO coating. It forms a self-ordered film with inter distances, $(D_{ma}) = 0.2–0.3 μm$, that is not achieved by MA, hence
commercially beneficial of processing time, 2500–3500% faster oxide film growth with high aspect ratios (>1000) of uniform nanopores with periodically modulated diameters.[17].

A simple and cost-effective approach of stable high-current density (1500–4000 A m⁻²) in a H₂PO₄–H₂O–C₂H₅OH system, by maintaining the self-ordering voltage and adjusting the anodizing high current density, to develop high-quality self-ordered HAAO films with a controllable inter-pore distance over a large range not solely dependent on the anodizing voltage, but is also influenced by the anodizing current density, with a high-speed film growth (4–10 μm min⁻¹) is very much suitable for commercial use [18].

Large area high quality self ordered AAO membranes has been developed in hours rather than days using high current density in a sulfuric acid solution, like the HAAO membranes [16]. With sulfuric, oxalic, phosphoric, tartaric, glycolic, malic and citric acid electrolytes, ordered nanoporous AAO films had been developed under 70–450V with arbitrary pore intervals from 130 to 980 nm on Al. The pore intervals of the porous alumina films has been found linearly proportional to applied potentials, with corresponding dominated territories to the electrolytes, the self-ordering extent of pore arrangehments has also been found improved with increasing anodizing potentials, leading to highly ordered porous alumina films at critical-high potentials. A cell separation phenomenon leads to the development of highly ordered alumina nano-tubule arrays for the films formed in sulfuric and glycolic acid media at the critical potentials ‘V’. The critical-potential anodization in the other mediumshad developed self-organized porous two-layered pore walls and pore bases alumina films[19].

Bycontrolling the pH acidity, ppm concentration, and °C temperature of electrolytes to get balanced growth of the barrier film layer and pore development, porous transparent alumina of desired D_int is achieved, the solar absorptivity or the transmittance α= f({D_int}, {V}) hence suggesting it may be suitable in SASCsdevelopment[19].

Increasing of the film thickness, decreasing of the average pores’ diameter, and distortion of pores enhanced the solar absorptivity of AAO SASCs. At an optimum value of pores’ area percentage the absorptivity had a maximum value enhanced by increasing of the incident angle [20].

The formation mechanism of precipitations under different anodizing conditions proposes low-temperature anodization, vigorous stirring and ultrasound-assisted anodization to reduce the hydrolysis product or hinder its deposition on the surface as well as inside nanopores of AAO. The ultrasound is very efficient to prevent the deposition of Al oxide hydrolysis product on AAO for realizing ordered AAO with clean surface [21]. The nano-coating approach gives better advantages, e.g. high quantum, large surface area, low costs of equipment, and more flexibility and control ways for ordered nanofilms with tuneable desired properties of transmittance, therefore more suitable for commercial development of SASCs compared to conventional methods e.g. lithography [22].

3. Research Methodof Thermography IRT Analysis

![Figure 1. (a) (b): Comparative Images of experimented specimens (a) Normal camera image (b) Thermographic camera (TGC)image](image)

Substrate material selected is M’s Hindalco branded commercial grade Aluminum Alloy series H1200 sheet of 0.71 mm thickness and seven flat strips of size~ 20 mm x 300 mm cut for hard and organic dyed non-hard Alumina (AAO) absorber flat surfaced specimens with varying R, 0.5–15.0 μm in bands width span of ~ 15 mm by roughening with #45-2000 emery papers on Aluminum substrate developed, put under the solar irradiations of single Sun as specimens # 2-11.
Dark colored non-HAAO blackened Aluminum flat substrate prepared by organic dyeing may be noted in specimens #9 & 10. The specimens’ details are listed in Table 1. The same is studied by thermography as shown in the Figures 1 & 20.

Table 1. Description of the specimen and lines shown in Figure 1[5]

| Specimen/ Line No. | Specimen Description |
|--------------------|----------------------|
| 1                  | Glass Surface as background, on which test specimen kept |
| 2                  | HAAO plain flat without Emery Papers roughening operation, Rₚ≈0.05 µm |
| 3,4,5,7            | HAAO flats with Emery Papers/45-2000 roughening operations, before anodising |
| 9,10               | Organic dye painted non-HAAO Aluminum flats after roughening operations with Emery Papers/45-2000 like Specimen #3/4/5/7 |
| 6                  | A4 size 75 grains m² white paper between glass sheet and specimen flats |
| 8                  | Line through specimen#7th flat and #6th paper for Line Analysis (LA) only |
| 11                 | Aluminum flat with Emery Papers application process prior to HAAO/chemical anodising processing of specimen #2, 3, 4, 5, 7, 9 & 10 for reference only |

The left side image in Figure 1 is a normal camera image of the set-up, whereas the right side image is the thermographic camera (TGC) image in which software for the spatial, temporal, and space-time scan statistics (SAT SCAN) is used to study the temperature profiles of the surface of the items under the experimental study along the lines drawn in the software upon the thermographic scanned image of the items for line-analysis. Both these images are kept side by side just for comprehension and ease of comparing. This camera software prepares graphs to show the temperature profile as shown in Figures 2 to 18 which are very useful for many applications including solar thermal power systems for PPE sanitization for COVID-19 prevention as discussed in this article.

4. Field Study and data capturing

The specimens were kept in Air-conditioned room at 24 °C before start of the experiment till 11:46 hours, so that the first solar field scan data (a) i.e. Ir 1 may closely represent their solar field performance in early morning hours where ambient temperatures are relatively low. The second solar field scan data (b) i.e. Ir 2 is near noon hours and may represent most of the day time peak solar irradiation data whereas the third solar field data (c) i.e. Ir 3 is afternoon near evening hours hence may represent the evening hours’ time data. The Specimens were already kept for many days together under the solar field in open atmosphere in summer and monsoon so that the specimen can represent nearly actual solar receiver like surface conditions in this study. The HAAO coatings developed on the specimens had been tested for a very long lasting performance of more than 5 years and hence are suitable for Solar Thermal Power Systems of Single Sun where systems and components need to perform for a longer duration to achieve better returns on the investments without losing their performance efficiency e.g. AIDHVACS. This study data may help in developing a better methodology for detailed solar thermal field studies of Solar Thermal Surfaces of various types of receivers in use at present or in future for striving at their better performance optimization.

The Lines L1 to L11 represents a representative data across the various specimens of Table 1. The software facilitates direct graphical representation of surface temperatures of specimens along the Lines selected for graph, maximum 4 lines per graph. Visually the Graphs represent Maximum and Minimum Temperature points or areas by color scale or right side of the scans, and their tabulated data from the software is directly obtained in output analysis.

In any thermodynamic system, the system efficiency may be compared with Carnot cycle efficiency, operating between the heat source and sink temperatures. To get the highest possible efficiency, heat addition from the source is desired to be at highest possible temperatures. In Solar Thermal Power Systems, the source is the solar irradiations, which are focused upon a solar thermal receiver. The surface of the receiver which faces and collects the solar irradiations directly is optimized to gain the maximum possible energy gain by various designs, in which solar selective coatings (SSCs) are on top priority of research[3-5]. The commercial production process parameters of the SSCs are of next step for which the mechanical operations and coating development process parameters are at main focus.In the present article, authors are studying HAAO surfaces prepared by mechanical operations e.g. emery paper rubbing and anodising with differential anodizing operational
parameters to differentiate various such HAAO surfaces to study any impact of such variations upon their solar thermal performance in the solar field applied under single sun using thermography camera scan analysis methodology; and also comparing it with organic dyed non-HAAO surfaces which may look like HAAO surfaces.

Figures 2 (a-c) show the field study of Table 1 Specimens in a day on 04.08.2018 at three different times viz. 11:53, 12:37 & 15:15 hours at Google map location 24°05’55.1”N & 82°40’21.4”E (24.09563, 82.672617) of NTPC Vindhyachal, India's Largest Super Thermal Power Plant, and is still continuing.

5. Field TGC IRT data analyses
The graphical data obtained in Figures 3-19 are observed comparatively for the surface temperature profile of various specimens at various timings in a day under a single sun solar field.

In Figures 2 (a-c) can be observed that the isotherm temperature scale is different in different times in the IR scans of TGC. The scale can be varied to obtain different area colors for visually examining relative temperature up or down with respect to the other areas of the TGC IR scan, referred as isotherm analysis technique. It is seen that Specimen #2 is best surface temperature gainer.

Table 2. Values of surface temperatures viz, maximum, minimum and average temperatures in °C along the line under the analyses, date: 4-Aug-18.

| Ir No.→ | 1 (at 11:53:53 hr) | 2 (at 12:37:18 hr) | 3 (at 15:15:48 hr) |
|---------|-------------------|-------------------|-------------------|
| Max. Temp. | 45.40 | 51.98 | 40.03 |
| L01:Max | 41.71 | 42.05 | 35.82 |
| L01:Min | 35.51 | 38.91 | 33.38 |
| L01:Avg | 39.31 | 40.62 | 34.64 |
| L02:Max | 44.95 | 51.89 | 39.90 |
| L02:Min | 40.21 | 46.03 | 37.08 |
| L02:Avg | 44.15 | 50.40 | 39.32 |
| L03:Max | 44.20 | 50.31 | 39.22 |
| L03:Min | 41.33 | 45.94 | 35.45 |
| L03:Avg | 43.23 | 48.36 | 37.90 |
| L04:Max | 42.89 | 48.22 | 38.75 |
| L04:Min | 39.14 | 43.71 | 34.77 |
| L04:Avg | 40.98 | 46.43 | 37.01 |
| L05:Max | 43.39 | 49.10 | 38.70 |
| L05:Min | 40.21 | 45.18 | 34.53 |
| L05:Avg | 42.11 | 47.71 | 37.45 |
| L06:Max | 37.78 | 40.53 | 34.38 |
| L06:Min | 34.40 | 37.39 | 32.35 |
| L06:Avg | 35.62 | 37.94 | 32.79 |
| L07:Max | 42.46 | 45.76 | 38.28 |
| L07:Min | 41.26 | 44.66 | 37.23 |
| L07:Avg | 42.06 | 45.09 | 37.78 |
| L08:Max | 42.82 | 46.55 | 38.72 |
| L08:Min | 34.74 | 37.36 | 32.80 |
| L08:Avg | 37.39 | 39.51 | 34.25 |
| L09:Max | 41.96 | 46.67 | 38.15 |
| L09:Min | 39.58 | 44.14 | 36.97 |
| L09:Avg | 41.06 | 45.75 | 37.68 |
| L10:Max | 41.46 | 45.83 | 37.81 |
| L10:Min | 39.71 | 42.30 | 36.68 |
| L10:Avg | 40.53 | 45.16 | 37.40 |
| L11:Max | 35.16 | 34.95 | 28.00 |
Table 3. Analysis of surface temperatures: maximum temperature along the lines

| Ir no. | 1 (ºC) | 2 (ºC) | 3 (ºC) |
|--------|--------|--------|--------|
| Max.   | 45.40  | 51.98  | 40.03  |
| L01:Max| 41.71  | 42.05  | 35.82  |
| L02:Max| 44.95  | 51.89  | 39.90  |
| L03:Max| 44.20  | 50.31  | 39.22  |
| L04:Max| 42.89  | 48.22  | 38.75  |
| L05:Max| 43.39  | 49.10  | 38.70  |
| L06:Max| 37.78  | 40.53  | 34.38  |
| L07:Max| 42.46  | 45.76  | 38.28  |
| L08:Max| 42.82  | 46.55  | 38.72  |
| L09:Max| 41.96  | 46.67  | 38.15  |
| L10:Max| 41.46  | 45.83  | 37.81  |
| L11:Max| 35.16  | 34.95  | 28.00  |

Table 4. Result of sorted maximum values of surface temperature along the lines

| 1 (ºC) | 2 (ºC) | 3 (ºC) |
|--------|--------|--------|
| L02:Max| L02:Max| L02:Max|
| L03:Max| L03:Max| L03:Max|
| L05:Max| L05:Max| L05:Max|
| L04:Max| L04:Max| L04:Max|
| L07:Max| L07:Max| L07:Max|
| L09:Max| L09:Max| L09:Max|
| L10:Max| L07:Max| L10:Max|
| L11:Max| L11:Max| L11:Max|

Figure 2. Thermographic Scans on 04.08.2018 at times with full view of experiment field scan process
(a) 11:15 i.e. Ir 1  (b) 12:35 i.e. Ir 2  (c) 15:15 i.e. Ir 3

Figure 3. Line Analysis LA-1 of Figure 2 scans of Line-1 (Indigo-Ir2, Red-Ir1 & Green-Ir3)

Figure 4. Line Analysis LA-2 of Figure 2 scans of Line-2 (Indigo-Ir2, Red-Ir1 & Purple-Ir3)

Figure 5. Line Analysis LA-3 of Figure 2 scans of Line-3 (Indigo-Ir2, Red-Ir1 & Purple-Ir3)

Figure 6. Line Analysis LA-4 of Figure 2 scans of Line-4 (Indigo-Ir2, Red-Ir1 & Purple-Ir3)

Figure 7. Line Analysis LA-5 of Figure 2 scans of Line-5 (Indigo-Ir2, Red-Ir1 & Purple-Ir3)

Figure 8. Line Analysis LA-6 of Figure 2 scans of Line-6 (Blue-Ir2, Red-Ir1 & Purple-Ir3)
Figures 9-19 show the line analysis of different line scans of the specimen surfaces. The tables (2-4) provide an analysis of pictorial and graphical data by values of surface temperatures, including maximum, minimum, and average temperatures along the lines under analysis. The XRF data of the specimens on a sample basis, developed from various processes of HAAO or non-HAAO coatings substrate and post-anodization processing, is shown in Table 6 for reference only. The detailed study may be presented in future, the same could be continued, the correlation of solar thermal properties of coatings with their metal composition prior and post the anodization process cannot be ascertained at this stage of limited number of specimen, instrumentation and IRT data.
Table 5. Specimen Sample $R_a$ (µm) before Anodisation from #45 to #2000 emery paper

| Bands | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|-------|----|----|----|----|----|----|----|----|----|
| $R_a$ (µm) (Mitotoya) | 9.24 | 9.09 | 0.99 | 0.81 | 0.77 | 0.76 | 0.59 | 0.47 | 0.44 |

From 45 to 2000 grade emery

6. Profilometry, Spectrography and XRF Results

The Profilometry data in Table 5 shows $R_a$ (µm) before Anodisation, one of the anodised specimens were tested by UV-Vis spectrometer Cary 4000 v1.12 and results of 200-900 nm spectra are graphed in Figure 21. It is understood from the data that artificially roughened specimen is showing less transmittance than the non-roughened, unprocessed specimen, in the wavelength range 200-685 nm which concludes that as the $R_a$ approached to nanoscale, the solar transmittance may increase, hence the surface temperature of such specimen could be higher, agreeing to the IRT data results. Full range solar spectrum analysis may reveal it.

Figure 21. Specimen’s UV-Vis spectrometer data (sample of two specimen)

Table 6. XRF data of specimens’ substrate and post-anodisation processing

| A: Avg value | R: Range | M: Metal | P: Atomic # | C: Periodic Table Column Position | G: Periodic Table Group Position | Substrate |
|--------------|----------|----------|-------------|---------------------------------|---------------------------------|----------|
| 99.145       | ± 0.375  | AI       | % 13        | 3A                              | 13                              | 97.89    |
| 0.635        | ± 0.265  | Fe       | % 26        | 8A 8                            | 0.5                             |          |
| 0.225        | ± 0.225  | Ti       | % 22        | 4B 4                            | 0.01                            |          |
| 0.18         | ± 0.18   | Mn       | % 25        | 7B 7                            | 1.15                            |          |
| 0.047        | ± 0.047  | Sb       | % 51        | 5A 15                           | 0.003                           |          |
| 0.045        | ± 0.045  | Cr       | % 24        | 6B 6                            | 0.07                            |          |
| 0.0305       | ± 0.031  | Cu       | % 29        | 1B 1                            | 0.07                            |          |
| 0.0305       | ± 0.031  | Ni       | % 28        | 10A 10                          | 0.02                            |          |
| 0.027        | ± 0.027  | Zn       | % 30        | 2B 2                            | 0.02                            |          |
| 0.025        | ± 0.025  | V        | % 23        | 5B 5                            | 0.02                            |          |
| 0.0165       | ± 0.017  | Pb       | % 82        | 4A 14                           | 0.02                            |          |
| 0.0145       | ± 0.015  | Ta       | % 73        | 5B 5                            | 0.02                            |          |
| 0.011        | ± 0.011  | Hf       | % 72        | 4B 4                            | 0.02                            |          |
| 0.0032       | ± 0.003  | Zr       | % 40        | 4B 4                            | 0.02                            |          |
| -            | -        | Si       | % 14        | 4A 14                           | 0.35                            |          |
| -            | -        | Mg       | % 12        | 2A 2                            | 0.02                            |          |

7. Analysis of IRT data

All the Specimens # 3,4,5,7,9,10 & 11 were mechanically differentiated for surface roughness $R_a$ along the length on one side only, with emery paper nos. 45, 60, 80, 100, 120, 150, 180, 220, 320, 400, 600, 800, 1000, 1200, 2000 & 2000 in total 16 bands of approx. 15 mm x 20 mm along the length of the
specimen#11 as shown in Figure 20. Initial lengths of 20mm and last length of 20mm left plain without emery paper rubbing operations by hand pressure. Total length of each specimen is about 300mm, width 20mm. The emery paper operation creates \( R_s \) range from 0.5 to 15.0 \( \mu m \) (measured by profilometer) where 0.5 \( \mu m \) value is of untreated surface and then \( R_s \) value may be ascending with respect to lowering of the emery paper number from 2000 to 45 in succession, gradually from right to left in the right image being seen in Figure 1, as shown in Figure 20 and Table 5 also. All the Specimens # 3,4,5,7,9 &10 were like specimen#11 before hard anodising process and are seen as in Figure 1 after anodising process. Specimen #7 got shorted in length as the other part of it got dropped in the anodiser bath tub solution while hard anodising, leading us to learn that thickness less then 1.05 mm of substrate Aluminum is sometimes not suitable for hard anodising process. Specimen #2 is HAAO from the same Aluminum flat piece like of Specimen#3,4,5,7,9 &10 but without any roughening process of emery papers i.e. \( R_s \sim 0.5 \mu m \).

The Table 4 shows that the maximum surface temperature is seen in the order of Specimen# 2>3>(4,5,7,9,10,11) throughout the day time, indicating that HAAO coatings are better to study sensitivity of surface temperature with respect to the surface roughness.

From the Thermo scan surface temperature plots of Specimens #2,3,4,5,7,9,10 &11 in Figures 3 to 13 it is observed that:

1. During the day, while the surface temperature gain from Morning to Noon hours, as seen in Figure 13 for Specimen #10 of Aluminum with roughened surface is not as high and as smooth as seen in other specimen which were HAAO or non-HAAO coated, either with or without emery paper roughening both, as seen invariably in Figures 3 to 10 as well as also seen in the result Table 4: the evening hour surface temperature drop from the noon hour surface temperature is also high in the non-operated specimen#11 as compared to the other HAAO or non-HAAO operated specimens; this indicates that HAAO and non-HAAO coated surface is better solar performer and sensitive than unprocessed surface, which means if the HAAO or non-HAAO coated surface loosens the AAO or organic dyed non-HAAO coating by any scratch or aging or anything else, thereby exposing the substrate surface of Aluminum thereafter, then the net surface temperature gain will be lesser in the solar thermal power systems, to the extent of damage of the surface coating area resulting in the exposure of the non-coated substrate Aluminum material. Therefore regular careful examination of the solar receivers is expected to expose the loss of solar thermal power system's efficiency. To clean the receiver's surface, it is desirable to use soft tissues of cleaning media to retain the surface coatings. Earlier experiments with HAAO surfaces with IR thermometer under single sun [3] have observed that at lower surface roughness index \( R_s < 1.8 \), the surface temperature gain is better than higher values of \( R_s \), probably due to peeling off the HAAO coatings and exposure of the Aluminum substrate to the Sunlight. The study result also confirms the results of the previous experimental macro-study observations [3].

2. The Surface temperature profiles on all the specimen # 2 to 11 are varying in the regime where emery paper roughening were imparted, with varying degrees as well, in Figures 3-13 as none of them are going as straight lines, hence suggesting sensitivity of the surface temperature profile with respect to the surface roughness factor \( R_s \) values of the surface. Therefore further investigation with respect to variation of surface roughness factor \( R_s \) and the surface temperature needs to be studied in detail to arrive at any optimal solution for \( R_s \). This can be understood as the possible deterioration or betterment of performance of coated surface of a solar receiver in the solar field, based on its \( R_s \) in the coating surface as well. In case the coated surface of a solar receiver is made with an optimal range of \( R_s \), then with the aging of the receiver, with changes in its surface \( R_s \) values, possible deterioration or betterment of performance of the solar receiver is expected. The surface contamination with dirt or anything else may further add-on the deterioration or betterment of the performance. This will further add the inherent variability of any solar thermal power systems. Mostly this factors is ignored in designing a solar thermal power system.

3. All the HAAO specimens # 2-8 and organic dyed non-HAAO specimens # 9 & 10 are unidentical with their HAAO or dye coating process operational parameters. Except the specimen
#2, all other specimen # 3-10 are developed from the same profile of the substrate specimen # 11 of Aluminum, therefore it is observed in Figures 14-19 that anodising process parameters also affect the degree of surface temperature gain hence suggesting more detailed study on optimal hard anodising or organic dyed non-HAAO process operational parameters for solar thermal power system solar receivers of HAAO or organic dyed non-HAAO coatings. From the result Table 4, it seems that among the specimens under the study, specimen #2 performing best, which were not roughened by the emery paper and had 'something better’ hard anodising HAAO coating process parameters. This indicates that in the mass production of the solar receivers, production system needs to control the hard anodising process operational parameters within close regime near to the optimal parameters so that the sample representative specimen can reliably exhibit the population of receivers to performance guarantee expected in the design. In some of the solar thermal power systems, it has been learnt that the system efficiency could not be actually performed after commissioning of the system, as per the expected level of performance in the design and bidding process, which has affected their return on investment and has not generated revenues to the system supplier.

4. Two lines # 1 and 6 are for validation purposes only which are on the background surfaces of the specimens viz. the A4 size white xerox paper on which all HAAO & organic dyed non-HAAO specimens are kept, and the plain glass on which the paper is kept with the specimens under the solar field. The glass is kept above a metal channel. The surface temperature profile of line 1 & 6 in line analysis plots LA-1 & LA-6 in Figure 3&Figure 8 shows background channel's temperature profile as well, which may or may not be effecting the surface temperature profile of the specimens, therefore measures have to be taken carefully in detailed study further to eliminate the error due to the background effect as well. In Ir-1 line which is Red in colour in both these LA-1 & LA-6, the lines have visible steep variations in surface temperatures as compared to Ir-2 Blue and Ir-3 Green or Purple lines, therefore when the specimen were taken out of the 24ºC air-conditioned room to the roof where the background glass were already there with the channel back ground, the background temperature difference between the glass and the specimens is clearly seen in Ir-1 profile. After about 44 & 202 minutes interval, the difference has been reduced to some extent but has not become near zero. For further detailed study, the specimens need to keep in the solar fields round the clock so that both the background and the specimens get the same cycle of solar irradiations throughout the day. It is important to note that both the glass and the paper surface are very much smoother than the specimens' surfaces, i.e. lower values of Ra can be expected in glass as well as the paper, still the temperature profiles in Ir-3 line of LA-6 as well as LA-1 are not straight lines, concluding that Ra value, however it be smaller, still imposes some surface temperature variations which may be very close to zero but not exactly equal to zero. This observation is best studied with presented technique through TGC as compared to any other technique available or in practice[3-6].

The isotherm scale quickly differentiates the portion of IR scan where surface temperature is above or below the set limit of the isotherm temperature scale. By varying this point of temperature on isotherm scale, isotherm analysis of TGC IR scan is done with more ease than the Line Analysis presented in the present study, which is more useful in solar power system receiver surface temperature profile analysis.

8. Results
In the current study, it is found that:
1. Not less than 1.05 mm Aluminum flat substrate is suitable for HAAO SASCs development.
2. HAAO SASCs are better to study sensitivity of surface temperature with respect to the surface roughness.
3. Polished, finished Al substrate surface (Rz<1.8 µm,~5-500 nm) exhibit better solar absorption in HAAO, surface temperature ~100 ºC may be achieved in single or multi sun, suitable for PPEs desensitization in solar air heaters applications [23-24], as noted on recent thermovision field
study on 01-07-2020, if composed with structured graphene which is having high selectivity [25].

4. $T_i$ is better in oxalic-acid mixed HAAO than only sulphuric acid based HAAO due to its better polished luster after anodization, hence recommended for solar air heaters in AIDHVACS.

9. Discussion
It seems that optimal range of $R_s$ is a matter of further detailed study for any particular solar thermal system application with HAAO coatings and with any other SASCs in general, since right now with the presented scope of work, the exact optimal range of surface roughness factor $R_s$ may be explored further, but it is seen favoring towards minimal possible $R_s$ value in a commercially viable production line i.e. $R_s \sim 0.05-0.005 \mu m$ which is achievable with present nano technologies. The intrinsic operation of hard anodization process itself increases $R_s$ value of the surface from nm scale to $\mu m$ scale as observed in latest specimens, which is beyond of the process control, however post hard anodizing, the HAAO coating may be polished again to lower down the $R_s \sim 5-50 \mu m$ which is the best possible solution for gaining the highest possible $T_i$. Post hard anodizing polishing gives glossy darker film coating of HAAO, whereas without polishing it remains matt and seen grayish. In earlier study [3], it has been found that for solar thermal applications, glossy darker HAAO coatings perform better than the matte grayish HAAO coatings, this may even need 2-3 times process of hard anodizing if substrate material thickness is 3.15 mm at least, since with less than 3.15 mm thickness substrate will lose its strength as seen it some latest other specimens’ development and analyses.

Heat dissipation in any solar receiver is a dynamic complex phenomenon having variability of solar irradiations and the environment, hence steady state flow characteristics of heat transfer medium is difficult to achieve which may even deteriorate the solar field performance of a SASC. Development of commercial grade HAAO coatings of 50-60 $\mu m$ for a flat solar receiver also needs a quick methodology to optimize the process parameters and receiver's overall design as well as to check the representative specimens for quality compliance to guarantee the performance in the solar field [26], hence the presented SAT SCAN software of a TGC is found suitable for the same. It is suggested to use XRF analysis of the SASCs for further probing the metallurgy factors affecting its solar field performance, since it is possible that in addition to the $R_s$ factor, glossy or matte surface finish factor, there may be change in material composition of the substrate due to the application of the emery paper or polishing or buffing wheel. The findings are in close agreement with similar study [27] on the bifacial (BF) $p$-type silicon ($p$-Si) passivated emitter and rear cells (PERCs) in which the rear surface morphology hardly affected the depth of local Al back surface field, the enlarged surface of rear side’s negative electrical impact area is more serious than that of front side; the efficiency of conversion in nine-busbar BF PERCs increases by 0.2 to 0.3 % as compared with five-busbar BF PERCs as a function of rear $R_{as}$, claiming highest average and peak efficiencies of 22.57 & 22.75 % in front-side nine-busbar BF $p$-Si PERCs with a $\sim$ planar rear surface $R_{as}$; and highest bifaciality of 78.7 % is with the roughest rear surface $R_{as}$.

The substrate material composition and surface temperature relationship may need further study for customized applications of AIDHVACS, which is the need of the hour to control COVID-19 in crowded area since the same is seen airborne, spreading indoors [28] and no biological hope to see an early eradication of the coronavirus in near future [29] therefore needs better engineering solutions [30].

10. Conclusion
Optimal $R_s \sim 0.05-0.005 \mu m$ for SASCs is possible in nano production technologies, but HA process itself increases $R_s$ from nm scale to $\mu m$ scale therefore post HA, SASCs’ buffing or polishing is necessary to keep $R_s \sim 5-50 \mu m$ for gaining highest possible $T_i$. Glossy darker HAAO SASCs may perform better than matte grayish HAAO SASCs, this may require repeated HA for which needs Al substrate thickness 3.15 mm at least, else the product will lose its strength. Thermography, Profilometry, XRF analyses of SASCs’ $T_i$& $R_s$& constituents quickly selects optimal commercial product process specifications for TPGSs e.g. AIDHVACS [28] which needs machine learning and big data analysis as the need of the hour to control the COVID-19 Pandemic [29] as well as to save the
environment [30] since "if we do not learn to cool ourselves the right way, we would essentially turn to cook ourselves".

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List of abbreviations

| Abbreviation | Description |
|--------------|-------------|
| AAO          | anodized Alumina (Aluminum Oxide Al₂O₃) |
| AI           | artificial intelligence |
| AIDHVACS     | artificial intelligence driven heating ventilation air conditioning system |
| BF           | bifacial |
| HAAO         | hard anodized Alumina (Hard-AAO) |
| HVAC         | heating ventilation air conditioning (system) |
| IR           | infrared (scan) |
| IRT          | infrared thermography |
| LA           | line analysis |
| MA           | mild anodization |
| PERCs        | passivated emitter and rear cells |
| PPEs         | personal protective equipments |
| p-Si         | p-type silicon |
| Rₚ           | surface roughness (of SASCs) |
| SASCs        | solar absorber surface coatings |
| SAT SCAN     | software for the spatial, temporal, and space-time scan statistics |
| TGC          | thermography camera |
| TPGs         | thermal power generating systems |
| Tₛ           | surface temperature (of SASCs) |
| UV-VIS       | ultraviolet–visible spectrophotometry |
| XRF          | X-ray fluorescence spectrometry |

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