The Effect of Mechanical Surface Treatment on the UV-Visible Reflectance of Low Cost Solar Thermal Absorber Materials

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ABSTRACT

The mechanical treatment of solar absorbers by rolling, surface roughening and polishing, and large scale texturing can significantly affect the absorption of solar radiation in the ultraviolet and visible range. In this study, the effect of a number of mechanical treatments was examined for a range of low cost absorber materials.

It was found that mechanical deformation of the test materials by rolling had a minor impact on their reflectance characteristics. However it was found that surface roughening and the orientation of the roughness features with respect to incoming radiation had a significant effect of the reflectance of all materials.

Keywords – surface texture, reflectance, absorber

INTRODUCTION

A major impediment to the wider spread use of solar energy devices is their initial cost (EECA, 2006). In particular, the wide spread use of expensive finned copper tubes with selective surfaces can be seen as a contributing factor to the high initial cost flat plate style solar water heaters. To overcome this there may be the opportunity to develop new collectors based on lower cost materials such as aluminium or steel (Anderson, 2010).Similarly, an increased interest in high temperature solar heating systems that could be used to generate high pressure steam present challenges to materials used in flat plate absorbers (Kennedy, 2002).

Now when considering the option of a change in the design paradigm of absorbers, with respect to the materials they are made from, it would also seem natural to explore how these metals could be tailored to deliver low cost solar-thermal components. One area of particular potential is through the development of low cost processing that can deliver very large area selective surfaces. The current methods for creating selective surfaces can be placed into six main categories: intrinsic absorbers, semiconductor-metal tandems, multilayer absorbers, metal-dielectric composite coatings, selectively solar-transmitting coatings on blackbody-like absorbers and surface texturing (Kennedy, 2002).

Although selective surfaces created by all six methods are being, and have been, researched and developed quite extensively, there has been some recent research that suggests there are still opportunities for developments based on surface texturing.

In a recent study Terheiden et al (2001) demonstrated that they could reduce the reflectance from silicon wafers over the visible spectrum by creating a V-groove surface texture using a conventional dicing machine fitted with a bevelled saw blade. Similarly, Weck and Leifhelm (2001), proposed a method of V-texturing photovoltaic cells, with a view to processing 12m^2/h of cells.

More recently, Konttinen et al (2003a and b) demonstrated the ability to create a $C/Al_2O_3/Al$ selective surface on an aluminium substrate using a two-dimensional random surface grinding process. It was suggested that, compared to current processes that require dangerous chemicals or access to capital intensive manufacturing facilities, that the process was relatively benign and low-cost.

At a more basic level, however, Tesfamichael and Wäckelgård (2000) showed that the fundamental processing of the base collector materials had an influence on the optical properties of their solar thermal collector. In their study of nickel based selective surfaces, they observed that the direction in which the substrate had been rolled, and hence the presence of “rolling groves”, could influence its reflectance properties.

In light of these observations, it was decided to further explore the impact that mechanical surface treatments had on the optical absorption of radiation by aluminium and steel, as potential low cost absorber substrates.

EXPERIMENTAL METHOD

In order to determine the impact of mechanical treatments on the optical properties of low cost absorbers two sample materials were chosen; a 5000 series aluminium and an interstitial free mild steel.

Each of these materials was subjected to a variety of treatments, with samples being prepared by two methods: firstly, samples were mechanically textured using a wet and dry paper of 80, 240, 1200 and 2400 grit, using water based lubrication; secondly, samples were cold rolled at room temperature then textured. In each instance, the direction of texturing was unidirectional as opposed to the random orientations used by Konttinen et al (2003a and b).

Subsequently, the surface roughness of the samples was measured using a surface profilometer fitted with a diamond stylus. In addition, the surface of the rolled samples was inspected by optical microscopy at 20x magnification, which showed a significant elongation of the grain structure post rolling, as shown in Fig. 1.

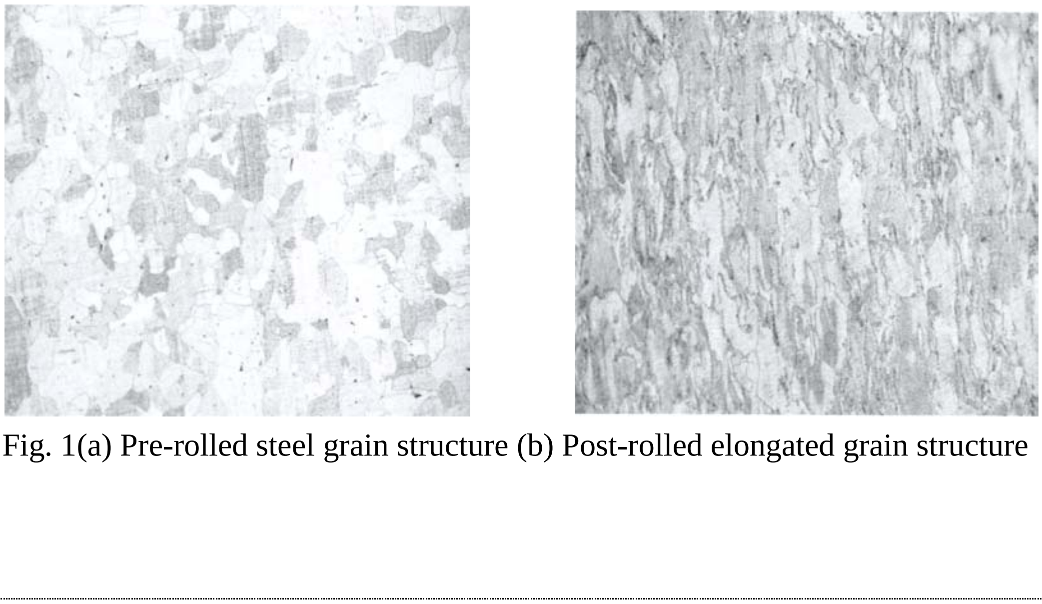

Fig. 1(a) Pre-rolled steel grain structure (b) Post-rolled elongated grain structure

After determining the surface roughness and optically inspecting the samples, the total hemispherical reflectance of the samples, between 260-700nm, was measured using a Datacolor 600 spectrophotometer in 10nm increments. The Datacolor 600 uses an 8º dual beam integrating sphere (six inch diameter) and a xenon flash lamp light source, as illustrated in Fig. 2. During all testing the spectrophotometer was fitted with a large area aperture, 30mm in diameter, to ensure integration of the reflectance over the maximum possible area. Calibration of the instrument was performed before testing using the white tile, green tile and black trap standards provided with the spectrophotometer.

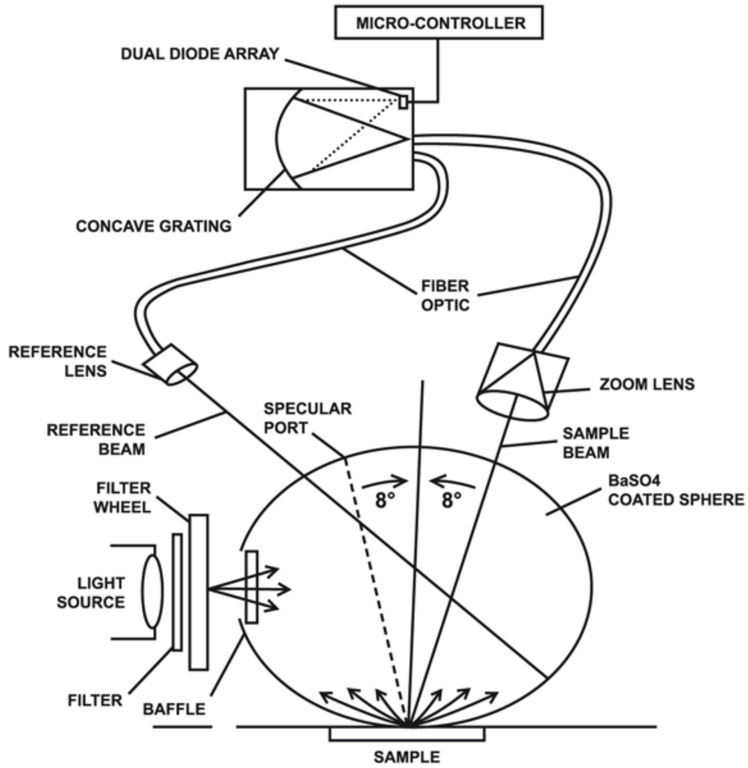

Fig. 2 Optical configuration of Datacolor 600 spectrophotometer (Datcolor, 2007)

EXPERIMENTAL ANALYSIS AND RESULTS

From the profilometery measurements it was found that, as expected, the coarse grit resulted in the largest roughness values of both the steel and also the aluminium samples. However, the roughness values for aluminium are much larger thus reflecting the fact that surface roughness is a measure of the arithmetic mean deviation of a short distance of a surface and, as a relatively soft metal, aluminium can be more easily abraded leading to larger surface roughness values. The values of the surface roughness for the samples are shown in Table 1.

Table 1: Sample surface roughness

Wet/Dry Grit	Surface roughness (R_a) (µm) - Steel	Surface roughness (R_a) (µm) - Aluminium
80	0.115	0.450
240	0.101	0.218
1200	0.022	0.126
4000	0.020	0.060

Now when inspecting the results from the spectrophotometry it was found that, as one might expect, aluminium had a much higher total hemispherical reflectance than the steel samples.

Additionally, it was found that the reflectance values of both steel and aluminium decreased with an increase in the wet/dry grit value, or with a decreasing surface roughness as shown in Fig 3 and 4. Moreover, it is interesting to note that, a finer polish (higher grit values) appears to provide an increase in absorption of shorter wavelength radiation in the steel samples. This is not observed in the aluminium samples which appear to change uniformly across all measured wavelengths.

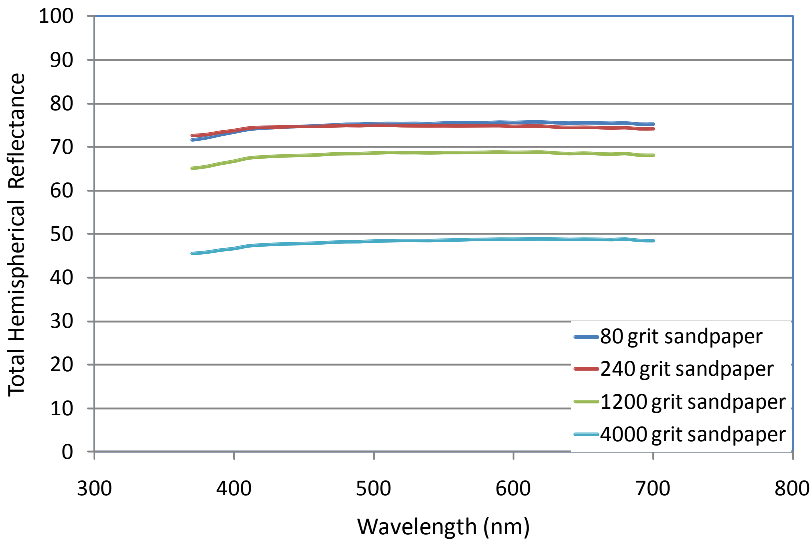

Fig. 3 Reflectance of aluminium with increasing wet/dry grit values

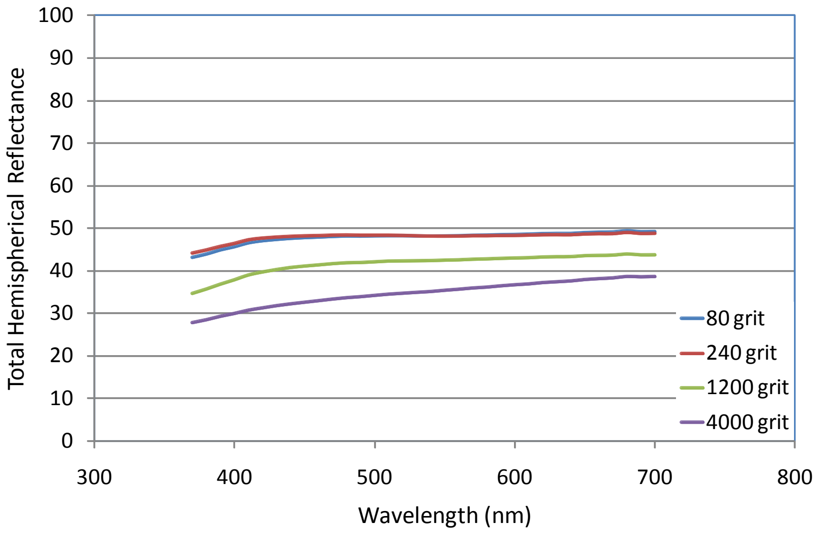

Fig. 4 Reflectance of steel with increasing wet/dry grit values

On first inspection these results would seem counter-intuitive, as one might expect a smoother (less rough) surface to have a higher reflectance. However, it is suggested that with a higher grit number, there is actually an increase in the frequency of scratching on the samples surface. This in turn leads to a greater number of opportunities for optical trapping by multiple reflections, though this hypothesis is still under investigation.

Now, in the literature (Konttinen et al, 2003a and b, Tesfamichael and Wäckelgård, 2000) it had been suggested that the processing of the substrate of a selective surface coated material could influence the reflectance of the absorber. As such, the reflectance of both rolled and non-rolled steel and aluminium samples with post roll texturing (80 grit wet/dry) were measured. In Fig. 5 it can be seen that the effect of rolling the material is relatively small in comparison to the effect of surface texturing with almost no difference in aluminium samples and a very minor variation in the reflectance of the steel.

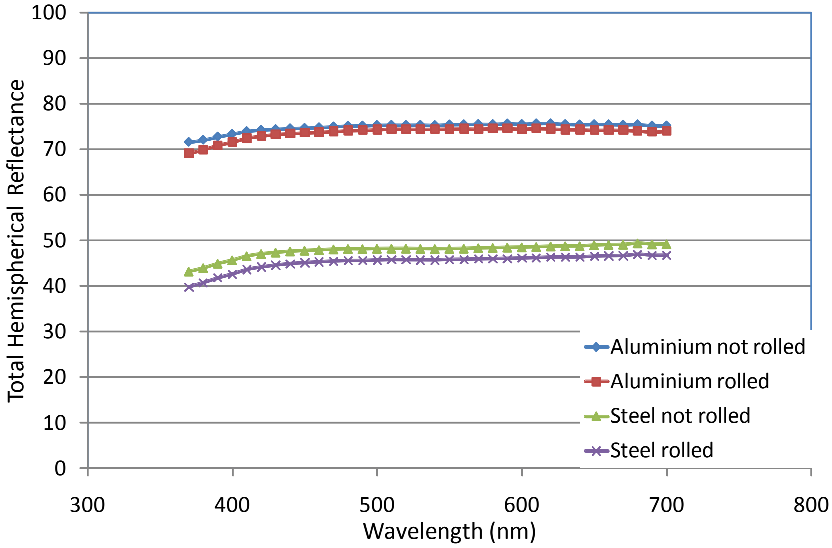

Fig. 5 Reflectance of textured samples with and without rolling

Similarly, it had been reported that there were directional effects associated with the orientation of rolling grooves in the literature. However, rather than examine this, it was decided to examine the directionality effects of the surface texture, as these had been created in one direction.

Now, to determine any directionality effects, the samples were rotated through 90° and their reflectance again measured. In Fig. 6 it can be seen that there is a marked difference in the reflectance of a textured (80 grit wet/dry) aluminium sample based on the direction in which the sample is oriented when taking the reflectance measurements.

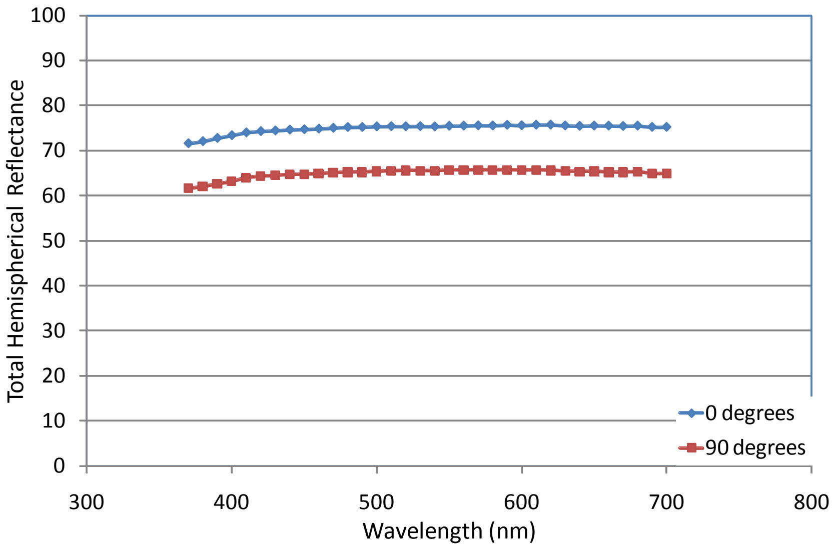

Fig. 6 Reflectance of textured aluminium samples with varying measurement orientation

The reason for this variation is that by reorienting the sample the surface texture features were oriented such the incident light would tend to be trapped by the texture features as shown in Fig. 7, remembering that the beam enters the integrating sphere 8º from the normal.

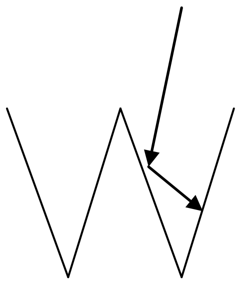

Fig. 7 Optical trapping in longitudinal surface texture features

As such, it can be seen that the direction in which surface texture features are created could have a significant influence on the absorption characteristics of solar absorbers and as such needs careful consideration when implementing.

CONCLUSION AND DISCUSSION

A desire to deliver lower cost solar absorbers necessitates a review of the materials and techniques that are used in manufacturing these systems. This study set out to examine how mechanical treatment of solar absorbers by rolling, surface roughening and polishing, and large scale textural deformation could be used to modify the absorption of solar radiation in the ultraviolet and visible range.

It was found that the reflectance of the absorber materials was not significantly affected by mechanical deformation by rolling. However, it was found that surface roughening and the orientation of the roughness features with respect to incoming radiation had a significant effect of the reflectance of both aluminium and steel as potential low cost absorber materials. More unusual it was found that the reflectance decreased with reduced surface roughness and there appeared to be an improvement in absorption of short wavelength radiation be steel with finer polishes, both these are areas that may require future work.

ACKNOWELEDGEMENT

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