Material determination using a thermal imaging camera

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ABSTRACT: This article demonstrates the use of a thermal imaging camera to read the heat signatures left on a ceramic tile after various steel sparks impact the tile. Ten different steels were compared, based on the hypothesis that different materials possessing different thermo-physical properties, should each produce a distinct thermal signature. Based on the research, one can conclude the hypothesis is true, but in order to positively identify an unknown sample, one has to exploit some other material properties using some simple tests, such as density, hardness, magnetic properties, spark length and angle of extremes of the sparks.

INTRODUCTION

A study of identifying common steels was conducted under the UGROW 2014 (Undergraduate Research Opportunities and summer workshop) programme at Midwestern State University. UGROW is a programme that allows undergraduate students to conduct research in a variety of disciplines ranging from the health sciences to engineering, under the supervision of their professors.

This material science based project was to determine whether or not one can identify different steels using an indirect method of spark testing. This research was also done to allow the average metal worker to identify unknown steels. In this experiment the sparks impacted a ceramic tile, allowing the tile to heat up; a thermal camera was used to see the thermal change the sparks had caused. The hypothesis was that the different elements in the metals would cause there to be a temperature difference between the metals. If the hypothesis is true the cost savings in identifying metals would be enormous and identifying different alloys would be fairly easy to do.

SPARK OBSERVATION, THERMAL STUDIES AND OTHER METHODS

History of Spark Testing

Spark testing began in 1909 and continued until the 1970s. The art of spark testing has been slowly dying out since then. A very experienced metal worker would place an unknown piece of steel against a grinding wheel and observe the sparks produced. The operator would then compare this to the sparks produced by known steels. The operator than determined from this the steel type. This process took years of experience to master and to be able to produce repeatable results [1].

History of Thermal Cameras

In this study, a thermal camera will be used to differentiate between the heat signatures of different steel samples. The hypothesis is based on different material possessing different thermo-physical properties and, therefore, each material would produce a distinctive thermal signature that can be seen by an infrared sensor [2]. Studies on thermal cameras and infrared detection began in the late 1800s; by 1913 the first patented thermal camera was produced and used for detecting icebergs. However, this study would not be possible without the more recent advent of uncooled thermal cameras [3].

Modern uncooled detectors use sensors that work by the change of resistance, voltage or current when heated by infrared radiation. These changes are then measured and compared to the values at the operating temperature of the sensor. Uncooled infrared sensors can be stabilised to an operating temperature to reduce image noise, but they are not cooled to low temperatures and do not require bulky, expensive cryogenic coolers. This makes infrared cameras smaller and less costly [4].

Experiment Setup and other Methods

In this study, a Fluke TiR thermal imaging camera, a Baldor model 8123WD eight inch bench grinder rated at ¾ hp and 3600 RPM, a coarse 36 grit grinding wheel, a custom built swing arm and a 4-in x 8-in American Olean quarry tile will be used. These can be seen in Figures 1 through 4.

Figure 1: Fluke TiR thermal imaging camera.

Figure 2: Balor 8123WD bench grinder.

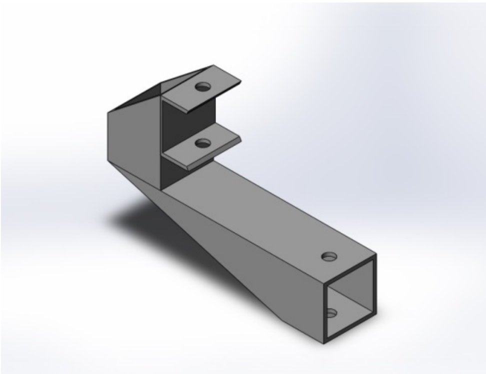


Figure 3: Custom built swing arm.

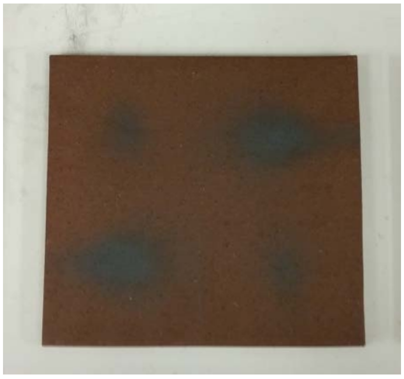


Figure 4: American Olean quarry tile.

In the experiment, the swing arm was attached to the bench grinder as shown in Figure 2. The steel samples were cut to a 0.5 inch diameter and a 3 inch length. The samples were mounted into the swing arm which allowed a constant contact angle and force against the grinding wheel due to gravity. This is shown in Figure 5.

Figure 5: Steel sample held against grinding wheel by swing arm.

The tile was placed in front of the grinding wheel allowing the sparks to travel a distance of 12 inches from the source of the sparks to surface of the tile as shown in Figure 6. The tile was exposed to 60 seconds of sparks before the thermal image was taken perpendicular to the surface of the tile. The sparks were stopped just before the picture was taken to allow the camera to focus on the tile. Figure 7 shows the use of the thermal imaging camera.

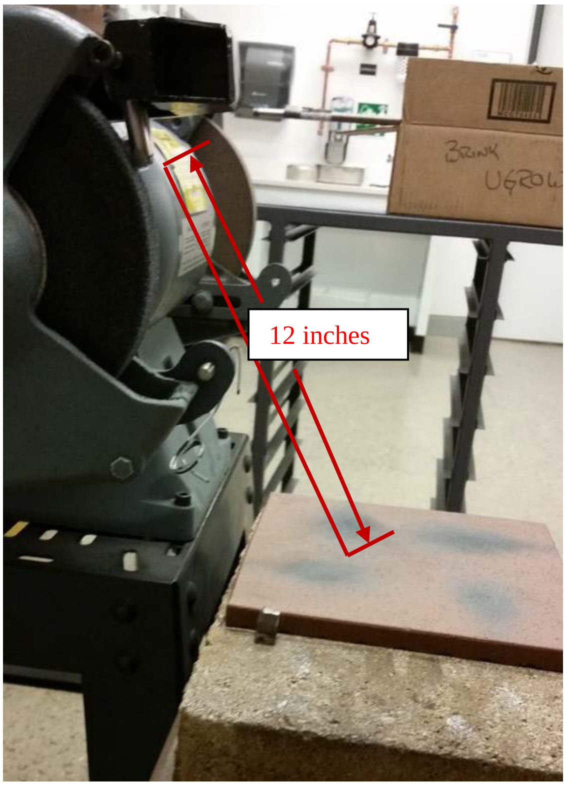


Figure 6: Experiment setup.

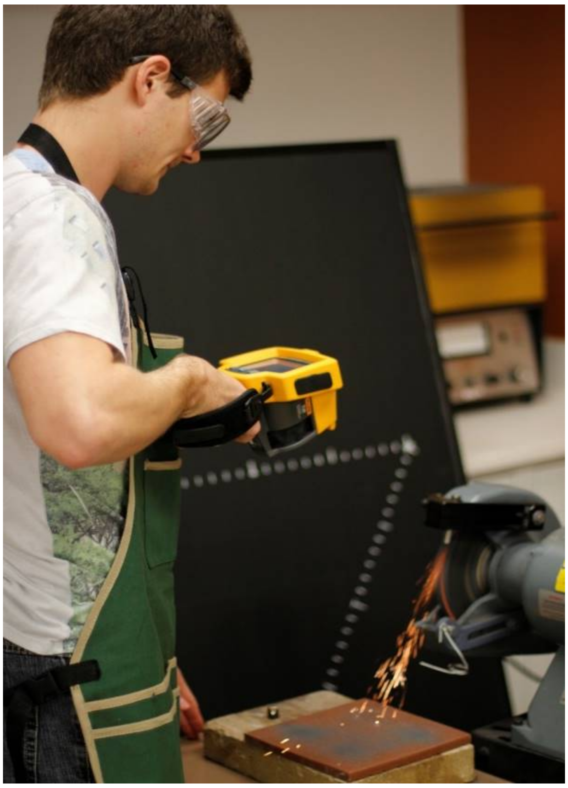


Figure 7: Use of the thermal imaging camera.

The first step in the experiment was to decide what type of surface one should use for the sparks to impact. The team first had to decide between an insulator and a conductor material. Figure 8 and Figure 9 show the insulator and conductor material, respectively. One can see in Figure 8 a very distinctive heat signature in the form of concentric rings.

This demonstrates a very good result. In Figure 9, no clear heat signature can be seen, this is because the conductor material absorbed all the heat from the sparks and dispersed it throughout the medium. The reflective qualities of this conductor material also caused the thermal reflections from around the laboratory to be picked up by the camera.

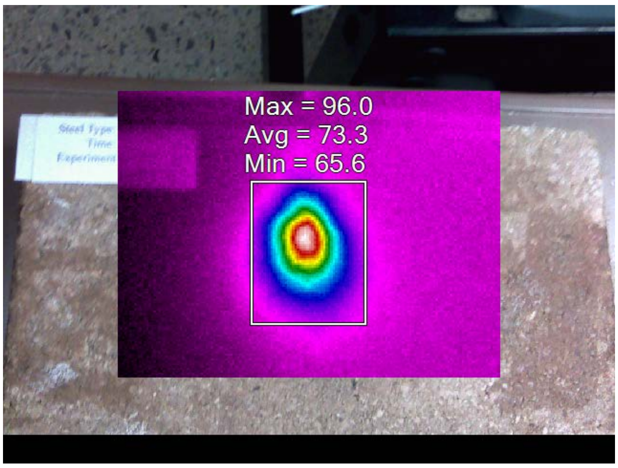


Figure 8: Concrete building brick after 60 seconds exposure.

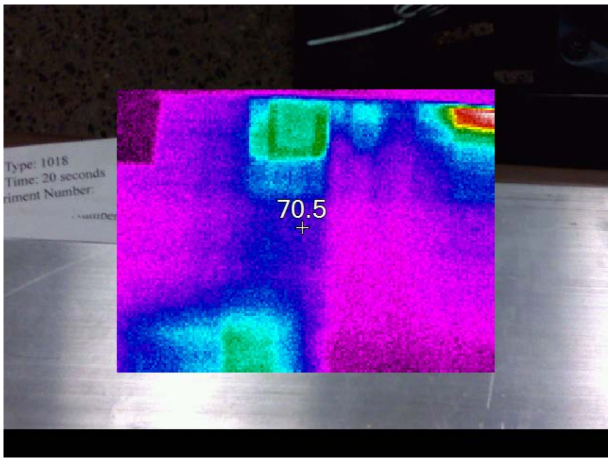


Figure 9: Aluminium plate after 60 seconds exposure.

Therefore, it was concluded that an insulator material would be better for this application because one can see a clear distinct thermal signature. Two other insulator materials were tested to find the one that had the lowest heat capacity. A lower heat capacity means that the surface requires less energy to raise its temperature; thus, a larger range of temperatures will be obtained. The material chosen was the American Olean ceramic quarry tile shown in Figure 4. The final result from one test using the tile is shown in Figure 10.

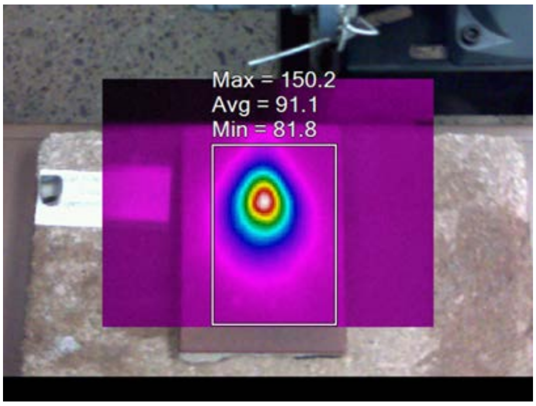


Figure 10: Quarry tile after 60 seconds exposure.

Using the quarry tile the following results were obtained, as shown in Table. 1

Table 1: Results obtained for 10 known materials.

Thermal testing, hardness and density results			
Steel type	HRC	Density (kg/m^3)	$T_{Max, 60s}$ (ºF)
Plain carbon steels			
1018	50.6	7854	118
1060	63.5	7664	103
Alloy steels			
1215	57.3	7773	141
4140	60.3	7760	98.0
4340	53.3	7764	87.4
Stainless steels			
17-4	79.3	7770	95.0
304	75.3	7864	87.0
316	78.0	7918	86.5
Tool steels			
O1	61.6	7789	126
D2	58.0	7650	84.0

From these results, it was concluded that the hypothesis is true. Materials possessing different thermo-physical properties do produce a different thermal signature. This is shown in Table 1 by the maximum temperature reached by the tile. There are several similar results that make it nearly impossible to positively identify many of the steels tested. This may be due to the accuracy of the camera and human error involved in taking the thermal image. The Fluke TiR has an accuracy of +/- 9 ºF and a thermal sensitivity of < 0.2 ºF at 86ºF [5].

A very similar maximum temperature was reached for the 304, 316, D2 and the 4340. One would be unable to positively identify the sample, when trying to identify an unknown sample that achieves the same temperature range as achieved by these four steels. Other material properties need to be exploited in order to identify the sample. They need to be material properties which the average metal worker can easily perform a test for.

Other material properties chosen to be analysed were their hardness, density and magnetism. One can differentiate between a stainless and non stainless steel by using a simple magnetic test to identify the sample. The 304 and 316 stainless steels are both relatively nonmagnetic compared to the others. Hardness and density are relatively easy to determine material properties. The Rockwell hardness C scale was used and the density was determined by calculating the volume of our cylindrical samples and their weight was measured using a Metler Toledo AG245 scale.

With these three extra material properties, a much more repeatable and accurate test to identify an unknown steel sample may be achieved. Unfortunately it still made it not possible to determine the type of steel of the sample in some cases. The UGROW 2013 programme at Midwestern State University used another two properties from another form of spark testing. Dalke et al found that the length of sparks produced and the angle of extremes produced by the sparks upon contact with a grinding wheel held in the same swing arm used in this experiment, are also a viable method of identifying steels, as shown in Figure 11 [6]. Dalke also concluded that using their method by itself produced similar complications as described in the current research. The similarities in the results obtained by them also made it difficult to positively identify an unknown steel sample. The current researchers like to propose a combination method of determining steels using thermal imaging, density measurements, hardness measurements, magnetic testing, spark length testing, angle of extremes measurements between sparks as a way to determine the type of steel specimen used. These results were combined into a database, and a Steel Identification Reference Manual was created. A page from this manual can be seen in Figure 12. This manual can be used as a guide to differentiate between these 10 common steels.

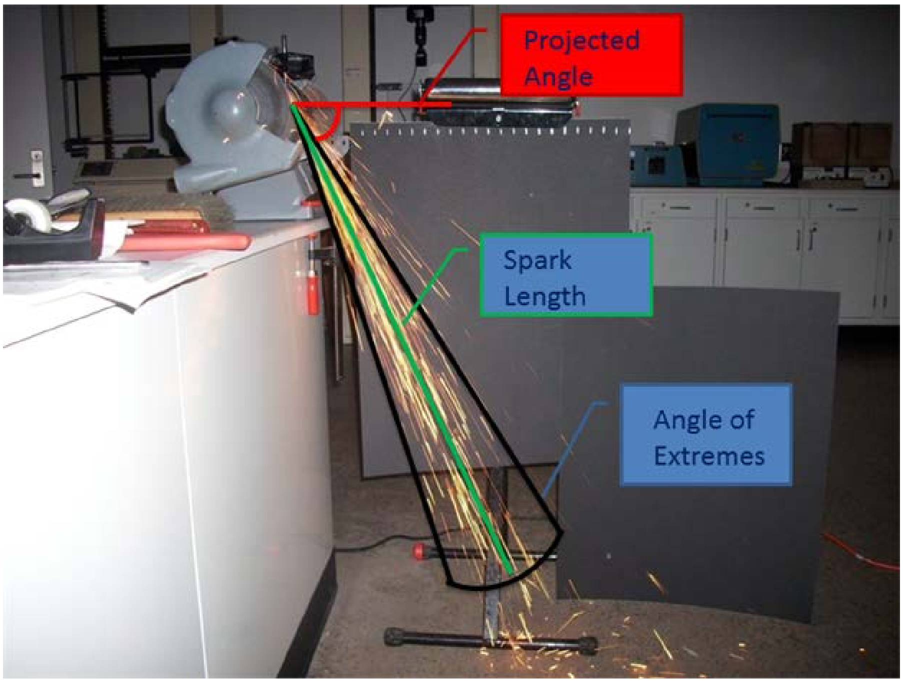
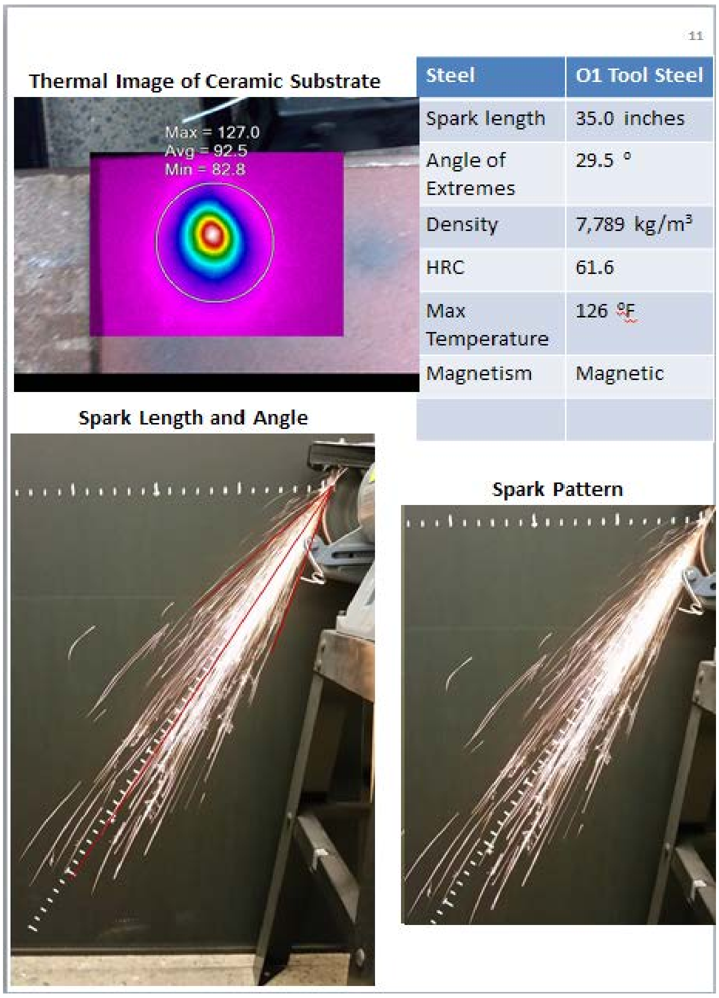


Figure 11: Spark length and angle of extremes.



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Thermal Image of Ceramic Substrate

Max = 127.0
Avg = 92.5
Min = 82.8

Steel	O1 Tool Steel
Spark length	35.0 inches
Angle of Extremes	29.5 °
Density	7,789 kg/m^3
HRC	61.6
Max Temperature	126 ºF
Magnetism	Magnetic

Spark Length and Angle

Spark Pattern

Figure 12: Steel Identification Reference Manual.

CONCLUSION

One can fairly easily determine an unknown steel sample specimen with the six tests described. This database can be expanded in the future for more steels.

FUTURE RESEARCH

Future research may include the use of a more accurate thermal camera to further test our hypothesis. This should increase both the accuracy and repeatability of the experiment [7]. Better repeatability of this experiment can also be achieved by using an automatic trigger mechanism on the camera, allowing for a constant time and distance for the camera to be operated.

A similar experiment could be done using a thermocouple and aluminium plate to test the average temperature increase due to sparks impacting the plate. Aluminium would be good for this type of an experiment because of its high thermal conductivity. In the future, the database can also be expanded to have a much larger range of steels.

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REFERENCES

1. Stookey, D. and Dargan, N., *Spark Testing Training Manual*. Manorville, New York: Island Steel Company, 1-9 (1967).
2. Ibarra, C., Tarpani, J. and Maldague, X., Nondestructive testing with thermography. *European J. of Physics,* 34, **6**, 91-109 (2013).
3. Bellingham, L., Means for Detecting the Presence at a Distance of Icebergs, Steamships, and Other Cold or Hot Objects. US Patent No. 1, 158,967 (1915).
4. Kreugle, H. *CCTV Surveillance Video Practices and Technology*. (2nd Edn), Butterworth-Heinemann, Elsevier Inc, 487-491 (2006).
5. Fluke, Thermal Imagers, User Manual. Fluke Corporation, 1-20 (2007).
6. Dalke, T., Brink, J. and Weller, M., Material determination using spark observation. *Global J of Engng. Educ.,* 15, **3**, 165-170 (2013).
7. Brink, J., Hinds, B. and Haney, A., Robotics repeatability and accuracy: another approach. *Texas J. of Science*. 56, **2**, 149-156. (2004).