http://doi.org/10.24867/JPE-2022-02-025

Journal of Production Engineering

Vol.25 No.2

JPE (2022) Vol.25 (2) Original Scientific Paper

Lanc, Z., Zeljković, M., Hadžistević, M., Štrbac, B., Labus Zlatanović, D., Baloš, S.

EMISSIVITY OF METAL SURFACE COATINGS

Received: 20 May 2021 / Accepted: 14 August 2021

Abstract: *As it is known, emissivity is paramount for accurate temperature measurement using IR thermography. The emissivity of metals is particularly interesting due to its variability in relation to surface conditions (surface roughness and oxidation state), viewing angle, temperature, and wavelength. In the frame of this paper, knowledge regarding metal surface coatings and its effect on emissivity has been gained in an effort to improve risk assessment of workplace burns arising from hot metal surfaces. The present study examined the emissivity of two-component polyurethane metal covering coat on steel and grey cast iron depending on temperature and coating thickness. It was concluded that metal coating leads to moderated metal heating and increases constancy of emissivity compared to uncoated metal surfaces.*

Keywords: *IR thermography, metal coating, burn risk assessment*

Emisivnost metalnih površinskih prevlaka. *Kao što je poznato, emisivnost je najvažnija za precizno merenje temperature korišćenjem IR termografije. Emisivnost metala je posebno interesantna zbog svoje varijabilnosti u odnosu na uslove površine (hrapavost površine i oksidaciono stanje), ugao gledanja, temperaturu i talasnu dužinu. U okviru ovog rada stečeno je znanje o površinskim premazima metala i njihovom uticaju na emisivnost u nastojanju da se poboljša procena rizika od opekotina na radnom mestu koje nastaju od vrućih metalnih površina. Ova studija je ispitivala emisivnost dvokomponentne poliuretanske metalne prevlake nenesene na čelik i sivo liveno gvožđe u zavisnosti od temperature i debljine prevlake. Zaključeno je da metalna prevlaka dovodi do umerenog zagrevanja metala i povećava postojanost emisivnosti u poređenju sa neobloženim metalnim površinama.*

Ključne reči: *IR termografija, metalni premaz, procena rizika od opekotina*

1. INTRODUCTION

Infrared measuring devices record infrared radiation emitted by an object and convert it into an electronic signal. Unlike pyrometer, as the most basic infrared device, which produces a single output using a single sensor, infrared (IR) cameras include an array of sensors to generate a detailed color image of the scene called thermogram [1]. Computation of temperature from data acquired with an IR camera is highly dependable on the emissivity of the target object [2]. The emissivity represents the ratio of the energy emitted by an object to that of a perfect absorber (blackbody) at the same temperature. It depends on both the properties of the substance and the frequency [3]. In addition to temperature and wavelength, emissivity can also be a function of emission angle [4].

The emissivity of metals is particularly interesting due to its variability in relation to surface conditions (surface roughness and oxidation state), viewing angle, temperature, and wavelength. Concerning this issue, it is suggested to use high emissivity coatings to significantly improve the thermal efficiency of metals prior to IR temperature measurement. Metal coatings are often used as one of the engineering control measure recommended by OSH as the most effective means of reducing excessive heat exposure when it comes to working near hot surfaces. Reducing the radiant heat emission from hot surfaces is usually achieved by covering hot surfaces with sheets of low emissivity material such as aluminum or using paint that reduces the amount of heat radiated from this hot surface into the workplace [5].

In regards to this international standard ISO 13732-1:2006 *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 1: Hot surfaces*, provides temperature threshold values for burns that occur during the contact between unprotected human skin and a hot surface. It deals with contact periods of 0.5 s and longer, and it is not applicable for a large area of the skin (10 % or more of the body skin surface or 10 % or more of the head skin surface), due to risk of burns of vital areas of the face. ISO 13732-1:2006 also describes methods for the assessment of the risks of burning using thermocouples for the temperature measurements of hot surfaces.

Keeping in mind that hot surfaces could be a large area, using IR camera for both measuring and monitoring temperature development of the entire surface, makes these devices an excellent replacement for the thermocouples. The problem arises from the lack of relevant data in terms of emissivity of coated and uncoated metals and its variability with temperature and coating thickness which contributes to a challenging application of IR cameras.

In the frame of this paper, knowledge regarding metal surface coatings and its effect on emissivity has been gained in an effort to improve risk assessment of workplace burns arising from hot metal surfaces. The present paper examined the emissivity of two-component polyurethane metal covering coat on steel

Note: The manuscript was presented at the 14. International Scientific Conference MMA held in Novi Sad, Serbia, 23.-25. September, 2021.

and grey cast iron depending on temperature and coating thickness.

2. MATERIALS AND METHODS

For the experiment, four workpieces of GJL-200 grey cast iron and four workpieces of the S235 structural steel were fabricated in dimensions 30×30×10 mm. Chemical compositions of the chosen materials are given in Table 1 and Table 2. Six workpieces were coated with a two-component polyurethane covering coat TOP PUR AY, manufactured by PITURA. The coating is characterized by high chemical resistance and excellent mechanical and esthetic properties. TOP PUR AY is resistant to the effect of solutions of certain acids, bases, salts and organic solvents, weathering factors and temperatures up to 150°C and it is mainly used as a covering coat for protection of buses, trucks, delivery vehicles, containers, wagons, etc. Prior to the application of TOP PUR AY, the workpieces were adequately prepared according to the requirements specified in the technical sheet. Each workpiece was previously cleaned of corrosion, oil, grease, dirt and polished.

% C	0.096
% Si	0.015
% Mn	0.800
% S	0.010
% Cr	0.021
% P	0.009
% Cu	0.013
% Ni	0.007
% Mo	0.002
% V	0.002
% W	0.002

Table 1. Chemical composition of the S235 structural steel

% C	3.050
% Si	2.580
% Mn	0.420
% S	0.100
% Cr	0.050
% P	0.068
% Cu	0.07
% Ni	0.020
% Mo	0.005

Table 2. Chemical composition of the GJL-200 grey cast iron

The roughness of the workpieces was measured with a contact method using a MarSurf PS1 device (Table 3). Grey cast iron and steel workpieces were coated in one, then in two and finally in three layers of coating in colure RAL 5010 (Gentian blue), in order to examine the influence of the type of material and layer thickness on the emissivity of coated metals during heating. Coating layers were applied using air spray painting technique where paint is applied to a surface via a spray gun, which is air pressurized. As can be seen from Table 3 with the number of coating layers, the surface roughness Ra decreases, except in the case where only one coating layer was applied. During air spraying of only one coating layer, it was noted that the covering power of the TOP PUR AY was very small. As the number of coating layers increased, the coating more evenly filled the surface of the workpieces, thus reducing the surface roughness. Coating thicknesses of workpieces were measured using Leitz Orthoplan light microscope. Prior to microscopy testing, the common metallographic preparation was conducted. It consisted of cutting, grinding (using a set abrasive papers from the coarsest to the finest) and polishing (diamond suspensions). Coating thicknesses are given in Table 4, while specimen sections showing coating layers are presented in Fig. 1 and Fig. 2, respectively, at 100x magnification.

Type of material	Ra [µm] without coating	Ra [µm] with coating
S235 structural steel	0.112	0.278 (1)*
	0.295	0.095 (2)
	0.232	0.106 (3)
GJL-200 grey cast iron	0.412	0.549 (1)
	1.563	0.474 (2)
	0.296	0.189 (3)

*number in bracket denotes the number of coating layers

Table 3. Surface roughness of the workpieces

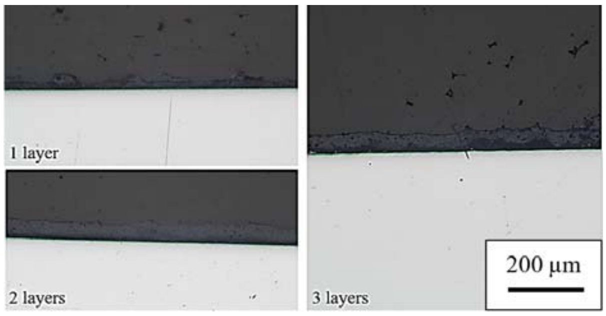

Fig. 1. Specimen sections of the S235 structural steel coating layers

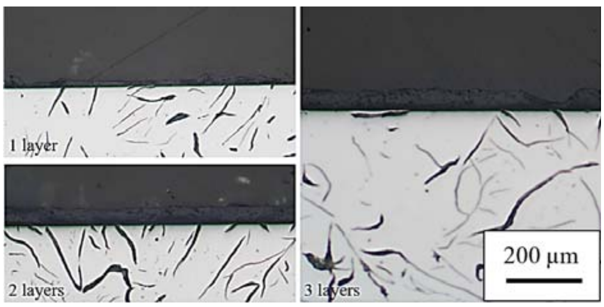

Fig. 2. Specimen sections of the GJL-200 grey cast iron coating layers

The emissivity of eight workpieces, two workpieces of steel and grey cast iron without coating and six workpieces with three different coating layers, was determined using experimental setup shown in Fig. 3. Methodology is based on simultaneous heating of a single workpiece, measuring the temperature using an

IR camera and type-K thermocouples. Thermocouples were placed in the center of the workpiece.

For the purpose of this paper, a heat-treat furnace was used for heating the workpieces. For obtaining and achieving a uniform temperature distribution on the surface of workpieces during the experiment, workpieces were placed upright in the center of the furnace in the special fireclay block.

Type of material	Average coating thickness [μm]		
	1 layer	2 layers	3 layers
S235 structural steel	20	40	50
GJL-200 grey cast iron	20	35	45

Table 4. Coating thicknesses of workpieces

The infrared camera used for thermal imaging was ThermoPro TP8S with a spectral range of 8–14 μm and temperature accuracy of ± 1°C. After installing the thermocouples and setting the IR camera, a workpiece was heated up to 100°C. During the heating IR camera recorded an IR image of the workpiece for each temperature increase by 10°C. Afterward, obtained IR images were processed using the Guide Ir Analyzer program where the emissivity of a workpiece was adjusted until the temperature on the IR image became equal to the thermocouple temperature.

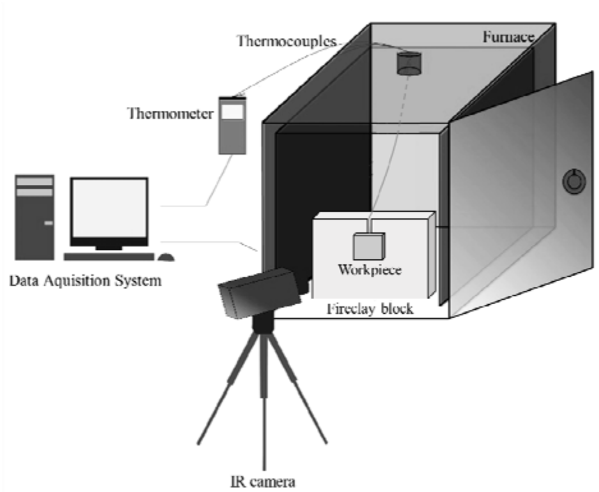

Fig. 3. Experimental setup

3. RESULTS AND DISCUSSION

The experimental data show that the emissivity (ε) of uncoated workpieces of the S235 structural steel and the GJL-200 grey cast iron slightly increases with temperature (T). The emissivity of the S235 structural steel ranges from 0.17 to 0.22, whereas the emissivity of the GJL-200 grey cast iron is higher and it ranges from 0.3 to 0.32 (Fig. 4). The differences in emissivity are due to the higher surfaces roughness of the GJL-200 grey cast iron workpieces as can be seen in Table 3.

IR images of the uncoated S235 structural steel workpiece presented in Fig. 5 shown highly reflective surface typical for metals that make it difficult to perform IR temperature measurement without using thermocouples as a temperature reference value. Oppositely, coated workpieces presented in Fig. 6 and Fig. 7 show a more uniform temperature distribution and no differences in the emissivity when it comes to type of material were noted.

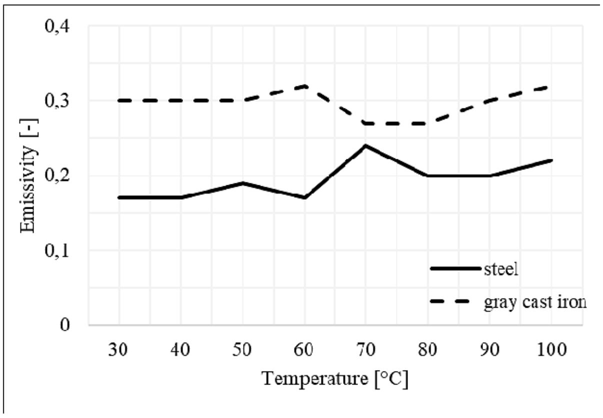

Fig. 4. Emissivity of the S235 structural steel and the GJL-200 grey cast iron without coating

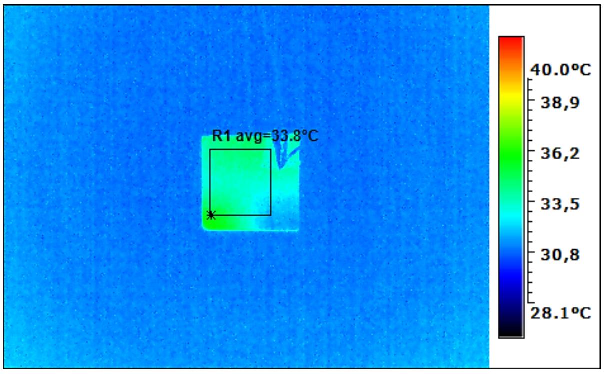

Fig. 5. IR images of the S235 structural steel workpiece without coating on 33.8°C (ε = 0.17)

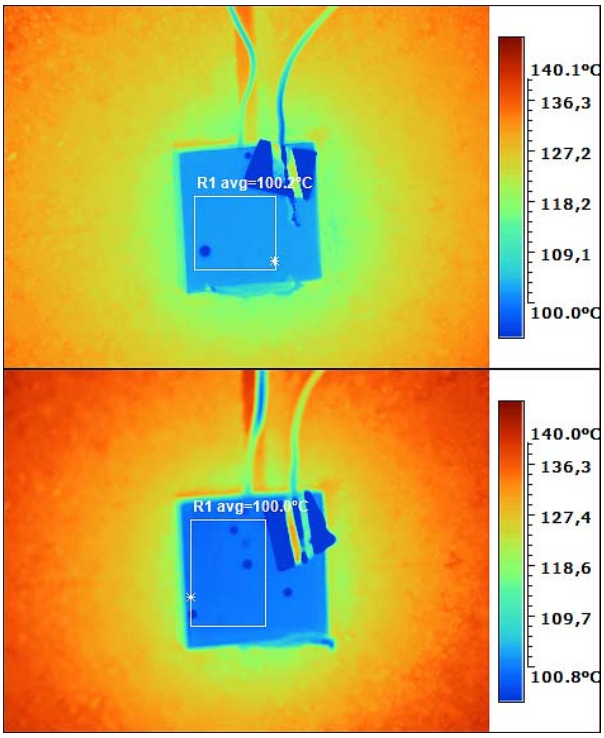

Fig. 6. IR images of the S235 structural steel workpieces with one and three coating layers at ~100°C (ε = 0.95)

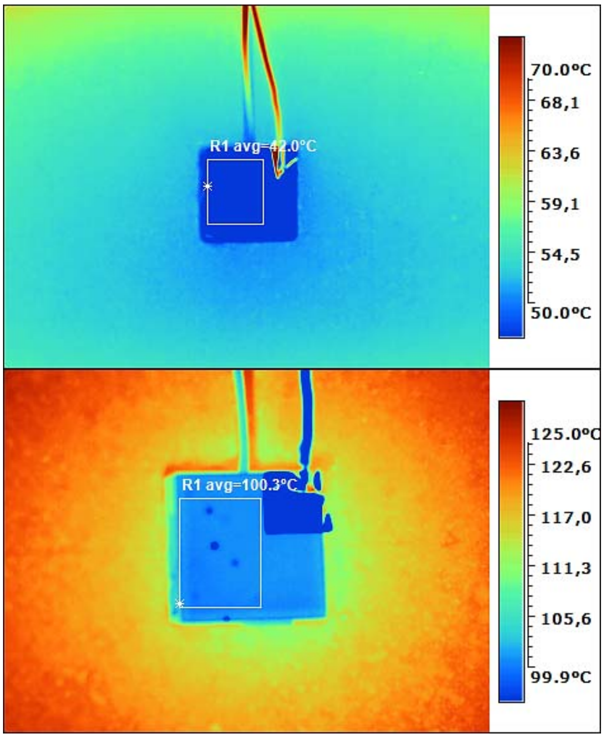

Fig. 7. IR images of the GJL-200 grey cast iron workpieces with three coating layers on 42°C and 100.3°C (ε = 0.95)

Moreover, the emissivity for coated workpieces was set to be 0.95 and remained constant during the whole experiment. The only difference between IR images of coated workpieces is that at higher temperatures the dust that settled on the coating during the drying is more noticeable. Dust particles can be seen on IR images in the circular form because of their contrast with the heated background. Due to their small size, they do not lead to significant changes in the average temperature of workpieces on IR images, leaving them corresponded to the temperatures measured by thermocouples. Interestingly, there is an evident difference in the temperature distribution on the fireclay block between S235 structural steel workpieces with one and three coating layers at ~100°C (Fig. 6). During the experiment, it was noted that the heating of workpiece with three coating layers required a longer time than heating of workpiece with one coating layer. This explains why the fireclay block is more heated in the first case, even when both workpieces are at the same temperature. Although the heating time is not accurately measured, it could be said with certainty that the tested coating leads to moderate heating of the metal.

Results show that the emissivity of coated workpieces doesn't change with surface roughness, coating thickness (Fig. 6), nor does it depend on the type of material. Additionally, there was no increase in emissivity with a rise in temperature (Fig. 7). Unlike uncoated metals, IR temperature measurement can be performed on coated metals without using thermocouples.

4. CONCLUSION

In the frame of this paper, knowledge regarding metal surface coatings and its effect on emissivity has been gained in an effort to improve risk assessment of workplace burns arising from hot metal surfaces of machines by using IR camera. The present paper examined the emissivity of two-component polyurethane metal covering coat TOP PUR AY on steel and grey cast iron depending on temperature and coating thickness and it is concluded that:

- the emissivity of uncoated S235 structural steel and GJL-200 grey cast iron is changeable and increases with temperature and surface roughness;
- the emissivity of the S235 structural steel ranges from 0.17 to 0.22, whereas the emissivity of the GJL-200 grey cast iron is higher and it ranges from 0.3 to 0.32 for temperatures up to 100°C;
- the heating of workpieces with three coating layers requires a longer time than heating of workpieces with one coating layer;
- coating leads to moderated metal heating compared to uncoated metal surfaces;
- coating increases emissivity of metal and keeps it constant during heating;
- the emissivity of coated examined metals is 0.95 and does not depend on surface roughness, coating thickness or type of metal.

These findings are valuable for the accurate IR temperature measurement which can be performed from a safe distance prior to burn risk assessment of hot metal surfaces of machines at the workplace. Keeping in mind that metal coatings are often used as one of the most effective means of reducing excessive heat exposure when it comes to working near hot surfaces, it is necessary to obtain certain knowledge regarding their emissivity. Considering that recommended emissivity values for metals are rarely given in relation to temperature and surface roughness, not to mention coating thickness, these results are helpful and much needed for improving burn risk assessment by means of IR thermography. Without having to use thermocouples to experimentally determine the emissivity, temperature measurement can be performed quickly on the entire surface of machine, not just on particular parts. On the other hand, temperature of uncoated metals can also be measured by IR camera, whether using it simultaneously with thermocouples during the burn risk assessment or by determining the emissivity, as described above, before the IR temperature measurement.

5. REFERENCES

[1] Usamentiaga, R., Venegas, P., Guerediaga, J., Vega, L., Molleda, J., Bulnes, F.: Infrared Thermography for Temperature Measurement and Non-Destructive Testing, Sensors, Vol. 14, pp. 12305-12348, 2014

[2] Mohr, G., Nowakowski, S., Altenburg, S., Maierhofer, C., Hilgenberg, K.: Experimental Determination of the Emissivity of Powder Layers and Bulk Material in Laser Powder Bed Fusion Using Infrared Thermography and Thermocouples,

Metals, Vol. 10, pp. 1546, 2020
[3] Vallero, D.: Fundamentals of Air Pollution 4th Edition, Academic Press,2007
[4] Zhao, W., Chellappa, R.: Face Processing: Advanced Modeling and Methods, Academic Press, Orlando, 2005
[5] https://www.ccohs.ca/oshanswers/phys_agents/heat_control.html

ACKNOWLEDGMENTS: Results of the investigation presented in this paper are a part of the research realized in the framework of the project: "Innovative scientific and artistic research from FTS (activity) domain", funded by the Ministry of Education, Sciences and Technological Development of Republic of Serbia.

Authors: **Ress. Assit. Zorana Lanc, Full Prof. Milan Zeljković, Full Prof. Miodrag Hadžistević, Assit. Prof. Branko Štrbac, Assit. Prof. Danka Labus Zlatanović, Full Prof. Sebastian Baloš,** University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485-23-24, Fax: +381 21 454-495.
E-mail: zoranalanc@uns.ac.rs;
milanz@uns.ac.rs;
miodrags@uns.ac.rs;
strbacb@uns.ac.rs;
danlabus@uns.ac.rs;
sebab@uns.ac.rs