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Nondestructive characterization of the tendency to chilling in cast iron using pulsed video thermography.

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Abstract

In this paper two thermal techniques are presented to characterize the tendency to chilling in gray cast iron. One technique uses the fact that the cementite phase of the cast iron material shows a thermal conductivity which is considerably below that of ferritic or pearlitic phases. The second technique is based on inductive heating of the specimen by an alternating magnetic field. In this case differences in the electric conductivity and in the magnetic permeability of the cementite and ferritic phases can be used in order to analyze the tendency to chilling in cast iron components.

1. Introduction

„Tendency to chilling" is a well known problem for the cast iron industry. „Tendency to chilling" means the undesired formation of ledeburite and cementite phases in gray cast iron due to imperfections in the production process. The hardness of the chilled areas is much higher than the hardness of the normal gray cast iron phase. This causes problems concerning the machining of the components and the service life of the machining tools is considerably reduced. The ductility of cast iron material in safety relevant components is of great importance. Therefore the tendency to chilling has to be avoided because it reduces the ductility of components [1].

2. Technique based on pulsed heating

2.1 Physical background

By pulsed heating of a large area of a specimen surface, a heat diffusing process into the material is induced according to the rules of the instationary heat diffusion theory. The heating and cooling process of the specimen surface stimulated by a heating pulse is essentially determined by the thermophysical properties of the material, namely the thermal conductivity and the heat capacity.

Any change in those thermal parameters will influence the heating and cooling process in a characteristic way. Due to the fact that the microstructure of a material influences the heat conductivity as well as the heat capacity, there will be the possibility to obtain information about the microstructure by means of a time-resolved analysis of the heating and cooling processes. In cast-iron material too, the thermal material parameters show a dependence on microstructure. Especially the cementite phase (Fe_3C) shows a significantly lower thermal conductivity than the ferritic or pearlitic phases. This fact can be used in order to analyze the tendency to chilling in cast iron material using pulsed thermography.

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2.2 Model calculations

In order to simulate the cooling process after pulsed heating and the measurement effect due to variations in the microstructure of the near-surface region, one-dimensional model calculations were used based on finite difference analysis. In the calculations it was assumed that the specimen consists of a ferritic-pearlitic substrate material and a chilled surface layer of thickness d. The calculations were done using different thicknesses d of the surface layer. Furthermore, it was assumed that the values of the thermal conductivity and the diffusivity of the chilled surface layer amounted to about 70 % of those of the substrate material.

The calculation results are presented in figure 1. Each curve shows the dependence of the temperature on the specimen surface from the beginning of the Gaussian shaped heating pulse (heating time 10 ms). The curve with the lowest maximum temperature is calculated for the case of a homogeneous material (for the case where no chilled surface layer is existing). The other curves are calculated for different thicknesses of the chilled surface layers.

From the curves one can see that the temperature maximum is reached after a short time (10 ms) and afterwards the cooling process is relatively fast and different due to the thickness of the chilled surface layer. The maximum temperature at the specimen surface is considerably higher in the cases of a chilled surface layer and the cooling process is the slower the thicker the depth of the surface layer. Hence we can conclude that the technique has the potential for a thickness analysis of chilled layers, too.

2.3 Measurement results

The experiments performed with a pulsed thermography testing system [2]. The measurement arrangement is presented in figure 2.

In these experiments a reference technique was used. In this technique the temperature distribution at the specimen surface, 50 ms after heating, was compared to the temperature distribution at the surface of a reference specimen of the same geometry. The specimens (step wedges) were made from nodular graphite iron with different thicknesses (from 5 mm to 25 mm; see figure 2). The various specimens were differently inoculated by a treatment alloy. Three different types of specimens were produced: one set of specimens was normally inoculated, another set was weakly inoculated, and the third set was not inoculated by the treatment alloy. So it was possible to produce chilled specimens (especially the not-inoculated specimen) with an increasing tendency to chilling in the thinner parts of the specimen.

In the thermographic images the temperature distribution at the specimen´s surface is presented at a definite time after the pulsed heating. The specimen were blackened in order to ensure a homogeneous emissivity near 1.0. Figure 3a shows the temperature distribution at the surface of two step wedges 50 ms after heating. A normally inoculated specimen is placed below a specimen which was not inoculated by the treatment alloy. The specimens are arranged in such a manner that the steps with the smallest thickness are on the left side. One can see that the temperatures of all steps of the upper specimen (not inoculated) are higher than those of the specimen below (normally inoculated).

Figure 3b shows the dependence on temperature (in gray values; 10 gray values ≅ 0.4 °C) along a line within the upper specimen (thin line) and one through the lower specimen (thick line). From this figure one can see that the temperature on the surface of the upper step wedge is decreasing with increasing thickness of the steps, while the temperature is nearly constant (if variations due to noise are ignored) along the normally inoculated specimen at the bottom. The enhanced temperature on the upper wedge is due to the tendency to chilling in this specimen which is caused by the fact that this specimen was not inoculated with a treatment alloy. According to the results of the model calculations the cooling process on the surface of a specimen with tendency to chilling is slower than in a specimen without the tendency to chilling due to the smaller thermal conductivity of the chilled material. Hence, in an early stage of the cooling process, the temperature on the surface should be higher in the

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chilled specimen. The fact that one can see a decreasing temperature on the surface of the chilled specimen with increasing step thickness can be interpreted as a reduction of the cementite content from step to step. This is in conformity with metallographic examinations of these step wedges (figure 5).

Figure 4a shows the temperature distribution (50 ms after heating) on the surface of a normally inoculated specimen (at bottom) and a weakly inoculated specimen (above). Figure 4b shows the temperature along a line through the normally inoculated specimen (thick line) and through the weakly inoculated step wedge (thin line). Along the weakly inoculated specimen one recognizes a decrease of temperature from the thinnest step (on the left side) to the thicker ones. Only at the two thinnest steps one can see on this specimen a little enhanced temperature if compared to the normally inoculated step wedge. This is due to the fact that, in the weakly inoculated specimen, chilled areas have been produced in the two thinnest steps, while the thicker steps show nearly no significant enhanced cementite content (see figure 5 with the corresponding metallographic image).

3. Technique based on inductive heating

3.1 Physical background

A second technique for a thermal analysis of the tendency to chilling is based on the inductive heating of the specimen. This technique uses a magnetic coil producing an alternating magnetic field. In the cast-iron specimens this field causes heating due to eddy currents and hysteresis losses. The eddy current losses in ferromagnetic material are dependent on the frequency and the magnetic field strength and are proportional to the material parameters magnetic permeability and the electric conductivity. The hysteresis losses are proportional to the magnetic permeability and are also dependent on the frequency and on the magnetic field strength. Due to the fact that the magnetic permeability as well as the electric conductivity of the cementite phase are less than those of the ferritic-pearlitic microstructure in cast iron, we can use this technique in order to investigate cast-iron material with tendency to chilling.

3.2 Measurement results

The technique was applied for the examination of the above-mentioned step wedges. Two step wedges (one reference specimen) were symmetrically placed within a special adapted magnetic coil and heated for one minute. The specimens were arranged so as to have equal magnetic field strength in comparable step regions of the two step wedges. Taking into consideration that the magnetic field strength of a coil is not constant along the axis, only regions of the two specimens which were excited by the same magnetic field were compared for an analysis of the influence of the tendency to chilling.

Figure 6a shows a thermographic image after one minute of heating of the two step wedges. On the left side one can see a step wedge which was not inoculated, on the right side a specimen with normal inoculation. A comparison of the surface temperatures shows that they are significantly higher on the steps of the right specimen. This can be interpreted by the fact that the specimen on the left side shows a tendency to chilling since it causes less heating due to a lower magnetic permeability and electric conductivity

4. Conclusion

In this work two thermal techniques - pulsed video thermography and thermography by inductive heating - were used in order to investigate the potential for the nondestructive detection of the tendency to chilling in cast-iron material.

The examinations have shown that both methods are suited to characterize qualitatively the near-surface microstructure - especially the tendency to chilling in cast-iron material. While in the pulse heating technique, the differences in the thermal properties of a material, especially

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the heat conductivity, are responsible for the measuring effect causing a higher temperature of chilled phases during cooling process, in the induction heating technique the heating effect due to eddy current and hysteresis losses is dominant in comparison to the heat conduction influence. Hence, due to the lower magnetic permeability and electric conductivity of the chilled phases in the region with a tendency to chilling, a lower temperature is shown compared to unchilled material.

At present a detection of the tendency to chilling is possible, especially by using the pulsed video thermographic technique on one side, contactless and fast testing, under the precondition that a reference specimen with the same geometry is available. Another precondition is that the surface of the specimens must show a homogeneous emissivity distribution (probably coated by a layer of black paint).

5. Acknowledgement

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REFERENCES

[1] PIWOWARSKI (E.). - *Gußeisen*. Berlin, Göttingen, Heidelberg, 1951.

[2] WALLE (G.). - *Impuls-Video-Thermographie*, Materialprüfung, Berlin, 1994, p. 86-88.

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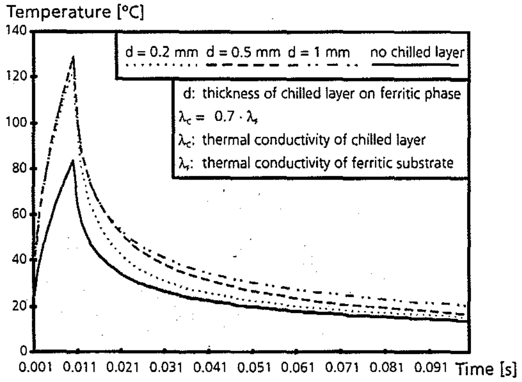


Fig. 1 Calculation of time dependence of the surface temperature of cast iron with different thickness of a chilled layer using pulsed heating

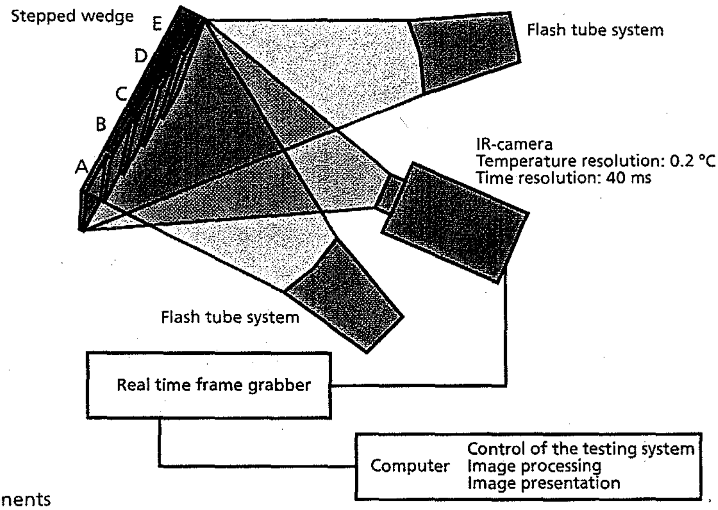
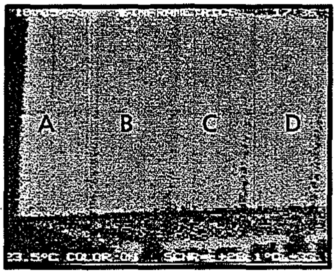


Fig. 2 System Components

Top: not inoculated



Bottom: normally inoculated

Fig. 3a Thermographic image of step wedges 50 ms after heating

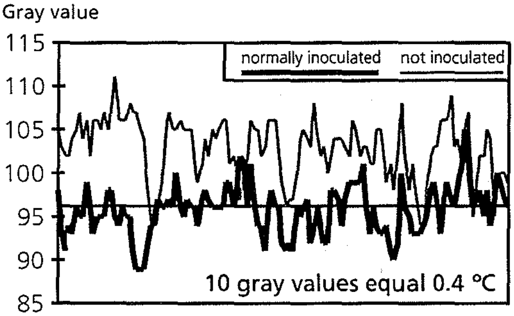


Fig. 3b Temperature distribution along horizontal lines

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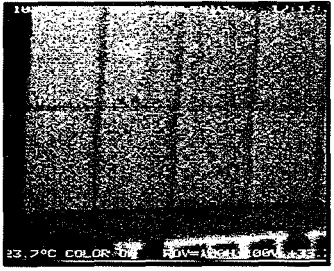
Top: weakly inoculated



Bottom: normally inoculated

Fig. 4a Thermographic image of step wedges 50 ms after heating

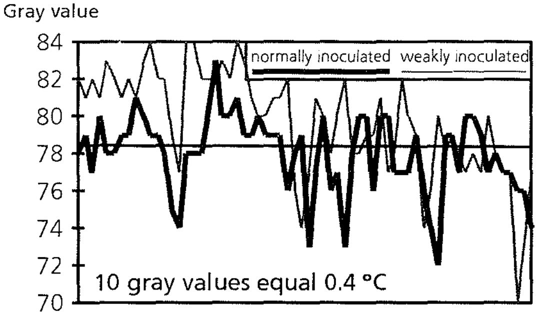
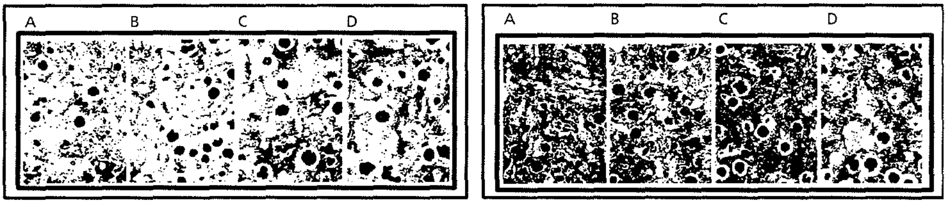


Fig. 4b Temperature distribution along horizontal lines

Metallograhic Images



Normally inoculated

Weakly inoculated

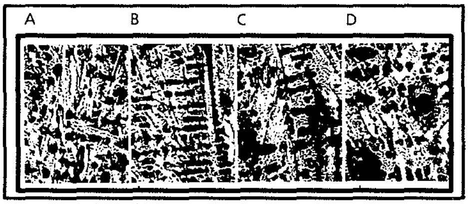


Fig. 5

Not inoculated

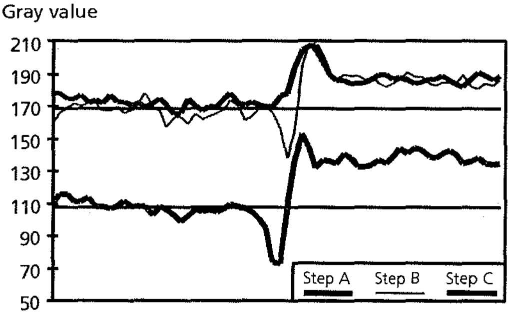


Fig. 6a Thermographic image of step wedges after one minute inductive heating

Fig. 6b Temperature distribution along horizontal lines