INSPECTION OF ALUMINIUM EXTRUSION USING INFRARED THERMOGRAPHY

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Abstract:
The paper presents the capability of an infrared thermography for surface inspection of hot aluminium extrusion. Monitoring the exit temperature of the extruded profile is the key component of the manufacturing control system. In hot metal forming technologies, the run of process and product quality are critically related to temperature. From the nature of aluminium forming, temperature is the important factor which affects the process kinetics and grain recrystallization within the material. The exit temperature of the extruded profile is usually applied as feedback value for the automatic control system. In that kind of solution only the information about local temperature value is required, which can be measured by special aluminium pyrometer. However global temperature distribution on the extruded profile surface contains information about the manufacturing process and also useful data for detecting defects. The analysis of the thermograms enables to find areas of temperature irregularity resulted from increased friction loads as well as areas of inhomogeneous emissivity caused by surface defects. In this paper, several algorithms for defect detection are described for both isothermal and non-isothermal processes. The proposed system consists of an infrared camera and computer based image analysis system. The analysis of thermograms acquired from infrared camera will enable surface inspection for detecting defects in temperature range from 400°C to 600°C. The proposed system can be applied in industry for in-line monitoring of aluminium extrusion processes.

Keywords: Infrared thermography, Surface inspection, Aluminium extrusion

1. INTRODUCTION

Aluminium extrusion technology is a multidisciplinary area of research. It is focused on thermodynamics, mechanics and tribology aspects of the material deformation process during the extrusion [1]. Although a number of advancement have been already made in this technology it is still a great scope of research. In the competitive market manufacturers are compelled to continuously improve extrusion speed, productivity and quality. Optimizing the process of extrusion it is very important to control the exit temperature of extruded profiles which is usually measured by using the special aluminium pyrometer. This variable is used as feedback value for the automatic control system. In that kind of solution only the information about local temperature is required. Nevertheless, analysis of the global temperature distribution on the extruded profile surface can provide much more information about the actual process conditions and for quality control. A direct and real-time analysis of thermal effects on the surface of extruded profile can provide useful data for defect detection. Applying an infrared camera for in-line inspection system enables to find areas of temperature irregularity caused by increased friction loads between the die surface and material [2], as well as areas of inhomogeneous emissivity caused by surface defects. The analysis of thermograms enables to find a number of defects in aluminium extrusion such as cracks, scratches, impurities, flakes. It can be also used for detecting die streak defect which appears after anodizing or painting aluminium extrusions. A number of defects in aluminium extrusions is presented in work [3].

2. MONITORING THE EXIT TEMPERATURE

Temperature disturbance of the aluminium leaving the die is a key factor for product quality and die life. It affects heat treatment process and also causes extrusion defects. Classically temperature measurement of the extruded profile is done by inserting a thermocouple into the die, measuring outside the die with a contact-type thermocouple or using an optical pyrometer. Contact methods have a limitation that temperature can be correctly read only when the extrusion is stopped or the speed of extrusion is very low. The disadvantage of inserting thermocouple into the die is a big response time so the automatic control system may not react properly for rapid changes in the temperature. For these reasons a noncontact temperature sensors are widely used in extrusion industry for constant optimization of extrusion process. The continuous monitoring of extrusion temperature enables the process to be operated as much as possible at a constant temperature by controlling the ram speed. If the actual profile temperature is lower than the demanded value, ram speed is increased by automatic control system. If the temperature achieves high limit ram speed is reduced. This technology is described as isothermal extrusion[1] and it has a practical advantages like reduction of production time, reduction in scrap, uniform metallurgical properties and dimension stability of extruded profiles. For properly embrace closed-loop extrusion it is important to comprehend definition of profile temperature[4]. Figure 1 shows that any extruded profile can contain a number of individual different surface temperatures in different points.

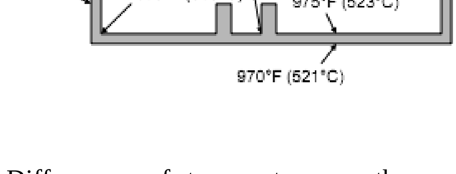

Fig. 1 Differences of temperature on the surface of extruded profile[4]

Depending on the profile shape the temperature difference in two points of a profile can be 10 °C at a given time. Applying an infrared pyrometer for monitoring the exit temperature of profiles it is crucial to guarantee a proper size of measuring spot of pyrometer. Nevertheless, extrusion of a number small profiles simultaneously using a multi cavity die may cause a problems for correct temperature measurement. The proposed solution for this issue is a computer based system with an infrared camera [5]. An experimental setup equipped with dual-camera imaging system was developed (Fig. 2).The method proposed in this paper uses of short wave infrared camera FLIR SC25000 that is suitable for temperature measurement on hot metal surfaces. A special vision module was equipped also with a visible high resolution CCD camera Basler. Both cameras are adjusted to acquire images of the area directly behind the exit from the heating chamber. The heating chamber enables to heat aluminium profiles to high temperatures above 500ºC, so a simulation of thermal conditions similar to aluminium extrusion processes is possible. In order to simulate the non-stationary process of inspection, the aluminium profile can be moved out of the chamber manually or using the linear actuator.

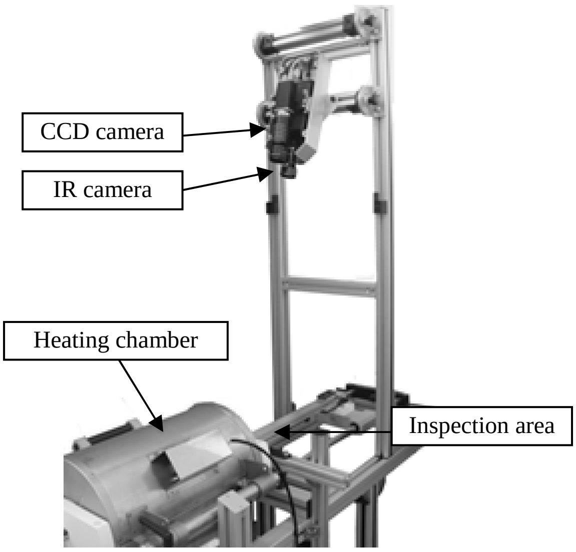

Fig 2. Photo of experimental setup

With a combinations of a set of exchangeable lenses and configurable software the system is suitable for a wide range profile geometries. The applied software enables to set-up a number of different size regions of interest where the temperature is measured.

Measuring aluminium temperature it is essential to evaluate a correct value of emissivity for analysed object in relation to infrared camera setup. The actual value of emissivity depends on many parameters including: surface structure, camera viewing angle, temperature, and wavelength of the infrared detector [6]. There are various methods of evaluating emissivity[7]. One of the most popular is to attach a tape or paint of known emissivity to the object under study. Assuming good thermal conductivity, the object emissivity is found by varying emissivity until the object temperature is equal to the known temperature of material attached. Evaluated value of emissivity is usually assigned to whole analyzed surface of profile but dealing with a multi cavity die extrusion process and profiles with complex geometry it is reasonable to consider several regions of interest (ROIs) on the generated emissivity map.

3. DETECTING DEFECTS WITH IR CAMERA

A number of defects in aluminium extrusion such as cracks, scratches, impurities, flakes can be detected directly on extrusion line. In this paper, a method for extrusion defects identification with use of an infrared camera is presented. Temperature irregularity observed on the 3D visualisation of thermograms [Fig. 3] of the extruded aluminium profiles can be associated with increased friction loads as well as areas of inhomogeneous emissivity caused by surface defects [Fig.4].

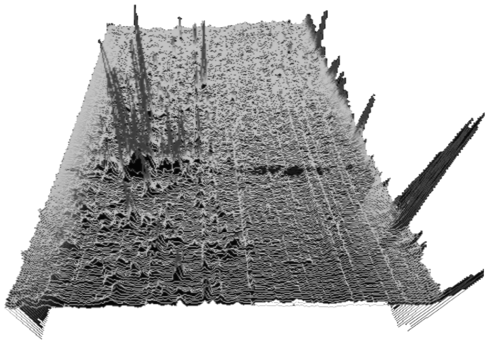

Fig. 3 Visualization of aluminium profile thermogram

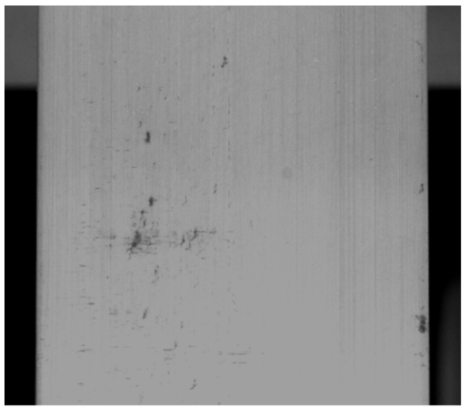

Fig. 4 Image showing the surface of aluminium profile

It is worth pointing out that analysis of thermograms for defect detection it is not quintessential to know the exact temperature of every pixel. The conversion from infrared camera readings to temperature units is adverse owing to lose of resolution. Therefore assuming homogeneous features of analysed surface it is not necessary to evaluate emissivity value. The proposed inspection algorithms are based on the segmentation function which is applied for detection of areas with deviation from average temperature of aluminium profile. Areas of temperature higher than assumed threshold are considered as hot spots and similarly areas with low temperature are marked as cold spots. Output matrix of the segmentation function is presented in Figure 5.

The average temperature value of the analysed surface can be calculated globally when an isothermal extrusion is assumed. However, during the extrusion with a constant ram speed the exit temperature can vary due to mechanics and thermodynamics of deformation process. Considering non-isothermal extrusion temperature base value for segmentation function is calculated for each horizontal line of the analysed thermograms. This operation is required to prevent errors resulted from deviation of exit temperature during the extrusion.

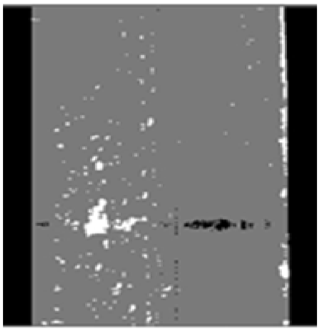

Fig. 5 Image of processed thermogram with hot (white) and cold (black) spots of temperature

To simulate this effect on the experimental setup aluminium profile is stationary preheated in the chamber and then moved out with a proper speed. This leads to increase of temperature during the translation of the profile [Fig.6].

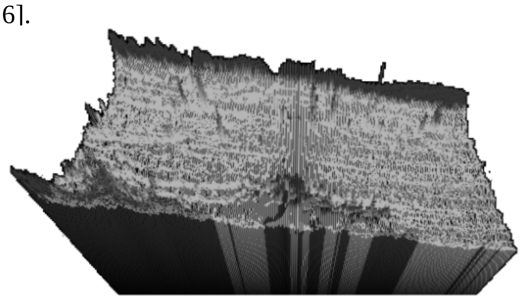

Fig. 6 Visualization of aluminium profile thermogram for non-isothermal process

The proposed segmentation function is meant to be insensitive to that kind of process variation. The matrix obtained by this method is an input image for an implemented inspection algorithms. The functions used for image processing and analysis are based on the OpenCV library[8].

3.1 Die Line Defect

One of the often described defects in aluminium extrusion process is a die line. It is defined as longitudinal depressions or protrusions formed on the surface of the extruded material due to imperfections on the die surface[3]. Specific kind of this defect is a micro die lines which occurs even with an optimum die land length and extrusion temperature, together with highly polished die lands.

Algorithm for detection of die line is designed as a counter of vertical lines which are observed in lengthwise on the captured thermogram. Analysing frame by frame appearance of that kind of features characterized by the same horizontal coordinate enables to detect potential die lines or micro die lines arise area.

3.2 Weld defect

Weld defect (Fig. 7) is similar to previous extrusion fault but occurring horizontally. It is caused by using a welding chamber to hold the back of the previous billet in the die and provide a surface for the next billet. In practice, the billet ends are oxidized which results with the billet-to-billet welding defect.

Fig. 7 Weld defect [3]

Assuming infrared camera orientations as presented in Figure 2, detection of this kind of imperfection can be done by identification of a waveform temperature changes spanned along perpendicular direction to the extrusion. In the first stage of the algorithm average of camera readings for each horizontal line is calculated. Outcome vector is a waveform that corresponds to actual surface temperature. Next differentiation is performed for detection of edges of the desired line. The areas of the analysed vector with the greatest changes have the largest absolute differential value. Two maximum values are searched after the threshold operation is applied. The detected pair of edges must also fulfil a condition of gap distance to be identified as weld defect. Classically areas where welding defects appear are predicted and cut out from the rest of the extruded profile. Nevertheless the propose method can be useful for detection of similarly looking defects which appear on areas not related with billet-to-billet seam but caused by momentary process instability.

3.3 Blisters and pick-up defects

Another extrusion defects which can be observed by infrared camera are blisters and pick-up defects. Blisters are surface imperfections caused by escaping gases during the lubricated extrusion. Pick-up defect is described as intermittent score lines of varying length range of 3-12 mm resulted inadequate homogenization treatment and die deflection. Both of these defects can be identified as stains in the output image of segmentation function [Fig 5.]. To stabilize detection of these defects several morphological operations are required for noise filtering and region filling[9]. Combination of erosion and dilatation functions is applied in the dedicated algorithm. In the next step blob detection is performed. Only the blob areas with proper size are identified as stain defects. In the next stage geometrical properties of these areas like moments are analysed and then selected stains are associated with blisters or pick-up defects.

3.4 Streaking defects

Thermal effects generated due to friction can result in inconsistent adhesion in the surface of the extruded profile. It was found that dynamic uneven recrystallization causes inhomogeneous distribution of grain boundary grooves which is reason for the formation of such defects as die streaks on anodized or painted aluminium extrusions [10,11]. Streaking defects on the surface of profile are observed as bands of lines which are darker or lighter than remainder of the surface As opposed to a previously described defects which can be detected directly on extrusion line by visible camera, die streaks are not visible before anodizing and painting. It is worth pointing out that it is not feasible to simulate that kind of faults in laboratory conditions. Nevertheless there are theoretical presumptions that these defects can be associated with increased temperature on the surface of extruded profile [12] which can be detected by infrared camera and identified similarly like previously described die line defect. The long-standings experiments carried out directly on the production line are planned for verification of the proposed method usefulness for detection of die streaking defects.

4. CONCLUSIONS

The method for the inspection of aluminium extrusion with infrared thermography was demonstrated. Experimental laboratory data and results showed in this paper indicated that the infrared vision inspection with the use of SWIR camera can be applied for on-line temperature measurements simultaneously with surface defects detection. Additionally monitoring the exit temperature of the extruded material can be done more effectively than in classical methods according to greater flexibility in measuring areas selection and functionality of applying multiple values of emissivity in desired regions of interest.

Laboratory tests of applied algorithms for defect detection proved that proposed infrared camera system can be an effective tool for monitoring aluminium extrusion process. High signal to noise ratio of acquired thermograms affirm that developed system can be an alternative for classical vision inspection methods. Additionally in some cases this method can give more reliable results for detection defects in subsurface layer and as it is for die streaking defect it may be the only way for identification of the product fault in on-line monitoring.

Information and quantitative measurement data obtained from the developed monitoring system can be use to control and optimize the process of hot metal forming. Further works will be focused on the development more effective algorithms and verification in industry for in-line monitoring of aluminium extrusion process.

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