Thermovision systems used to improve a technological process for hot-rolled copper and brass strips

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Materials

ABSTRACT

Purpose: This paper contains description made on thermovision testing with the use of Inframetrics 760B system. Measurements were executed on the surface of a heat furnace and also on the surface of material heated before and hot-rolled. The results of the investigations in a form of thermograpic pictures were taken down in working environment.

Design/methodology/approach: The purpose of this research was to evaluate technological process of heating cooper and brass cakes, and hot-rolled strip in special passes assessment of the temperature modification. For basic criterion estimation of these processes, the maintenance at the demanded final rolling temperature in order to keep up adequate structure and narrow range of mechanical properties variation was accepted.

Findings: The process of heating charge material is carried through in order to facilitate its machining in a rolling process. When the material does not obtain the adequate temperature or does not become uniformly heated, internal stresses which cause appearance of the rims of fracture and occurrence of other defects in structure appear in cold rolling, as the next. Because of this there is a need of temperature controlling.

Research limitations/implications: If a temperature profile on heated to a hot-rolled cakes is not uniform and does not reach a given level, this can mean forming some defects, which can be revealed during a hot-rolled process, relatively during following technological operations leading to a quality decrease and in a consequence to product disqualification

Originality/value: The use of thermovision system in processes of heating cakes evolution and also hot-rolling. These research enable a condition control of thermal furnace and hot-roll processes.

Keywords: Metallic Alloys, Copper, Brass, Cake, Hot-rolled, Furnace, Thermovision, Thermograms, Infrared

1. Introduction

The contemporary achievements in a material engineering domain and quality engineering enable designing, conducting and a control of flexible technological processes. The ability to introduce a new production technology and quality inspection in accordance with demands, presents a basis to keep up the market. Dynamic changes in production extort the necessity of applying some tools and technologies assuring the fastest adaptation to new realities [1-3].

Obtaining a high quality and competitiveness products production is connected with a necessity of continuous controlling and basic technological strip improvement as well as the entire manufacturing process. The analysis and limitation of energy loss is one of essential problems. Nowadays, there is a variety of systems and technique measurements applied to check technological process parameters, however each of them due to their own characteristics (construction) has application restrictions.

It is different about thermovision systems, which for the sake of their versatility (a passive and active method) and possibility to measure from further distance, let a considerably wider spectrum of use [4-7].

Thermography utilization in different technique fields becomes more common nowadays [8-10]. It is applied in ecology, medicine, rescue operations, building engineering with observation of thermal processes, for instance in quality and quantity assessment, as well as in material research or monitoring productive processes, where heat is produced or received [11-13].

Application of thermovision methods with considerable limiting outline devices and manufactured products is highly universal, because all measurement activities can be conducted during a continuous device operation, without stopping a production cycle.

2. Description of the approach, work methodology, materials for research, assumptions, experiments etc.

The purpose of this paper is to present a possibility to estimate industrial of technological heat processes and consequently, hot-rolled cakes applying thermovision system.

2.1. Research methodology

Figure 1 presents a block diagram of following procedure stages while conducting one's own research.

Within a framework of realized research by means of a thermovision system - Inframetrics 760B, distribution of temperature was determined onto: surface of a heat furnace case in a heating process of cakes, surface of cake directly after heating to rolling temperature, copper and brass surface cake during a hot-rolled process (after following passes) on a two-high reversing mill.
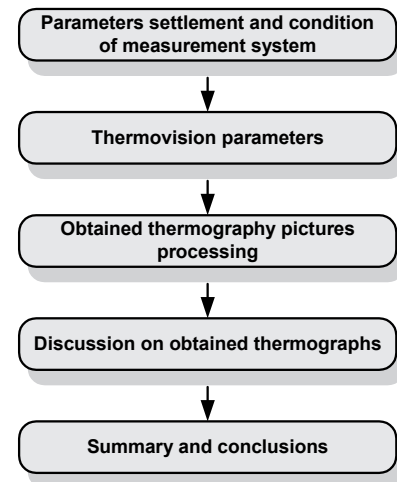

Fig. 1. Stages of research

2.2. Testing materials

There were used some copper cakes of M2R grade and brass cakes of M63, M66, M67, M70 grades [10] into investigations. The chemical composition of cakes was consistent with obligatory standard PN-EN.

The dimensions of testing cake: a thickness 140 mm, a width 750 mm, a length 7000 mm, an average cake mass 6000 kg.

Cake destined for hot-rolling should be characterized by uniform heating in the whole volume. The temperature before rolling should be equal appropriately: for cake made of brass M70, M68 780°C - 820°C, for cake M66, M67 750°C - 800°C, for cake M63 740°C - 780°C, for cake M2R 850°C - 870°C.

2.3. Devices

The cake was heated in a gas-fired walking beam furnace. Loading the cakes into the furnace means packaging them on a special grate by the entrance keeping adequate order and direction (for the sake of casting). The direction of location assured starting the cake rolling from a head side. During this process the cakes are heated following the company scheme (each grade separately) for the sake of characteristics materials (thermal conductivity factor, thermal expansion, heating temperature). The uniform heating of cakes all their length down and section must be connected with a rolling tact. Heating control and cakes displacement in a chamber of furnace is conducted with the help of a computer program, which main aim is to assure equal intervals between cakes in a furnace chamber. Onto thermal quality of cakes significant influence is exerted on a proper adjustment of burners operation in individual heating zones (consistent with an obligatory heating program). The walking beam furnace has got seven independent heating zones, but temperature in each of the zones is regulated by an adequate (for a charge material) thermal computer controlled program.

The cakes were hot-rolled on a universal rolling mill, which was equipped with vertical rolls, adequately long rollways carrying away the load, and also with a cold store and a strip coiler. Table 1 presents a roll pass diagram during hot-rolled brass cakes.

Table 1.
Diagram of roll passes for brass cakes

Roll pass number	Thickness [mm]	Deformation		Rolling speed [m/min.]	Strip length [m]
		[mm]	[%]		
0	140.0				
1	114.0	26.0	18.6	75	8.3
2	90.0	24.0	21.0	75	10.5
3	70.0	20.0	22.2	75	13.5
4	55.0	15.0	21.5	75	17.3
5	42.5	12.5	22.7	90	22.3
6	32.5	10.0	23.5	90	29.2
7	25.5	7.0	21.5	100	37.5
8	20.5	5.0	19.6	120	46.2
9	16.5	4.0	19.5	135	57.5
10	13.5	3.0	18.2	145	70.0
11	11.5	2.0	14.8	145	82.5

The diagram of rolling passes for cooper cakes is characterized by different steps of deformation in following rolling passes, this is a subject to whether rolls are hot or cold.

For hot rolls apply a diagram of roll passes: 140 - 109 - 84 - 63 - 47 - 35.2 - 26.4 - 19.8 - 14.5 - 11.5 mm applies.

In a case of cold rolls: 140 - 114 - 90.0 - 70 - 55 - 42.5 - 32.5 – 25.5 - 20.5 - 16.5 - 13.5 - 11.5 mm.

The product, being a result of rolling is a copper or brass strip with dimensions: a thickness 10 – 11.5 mm, a width 700 - 780 mm, a maximum length 95060 mm

2.4. Measurement apparatus

When conducting a thermovision system Inframetrics 76B research was used, consisting of a thermovision camera and interception modulus (control and setting measurement parameters). The essential was to use a limitation of the applied thermovision system - Inframetrics 760B to dynamic research, it is a character of performing measurements, i.e. a picture is scanned (a bundle is sent, and next it goes back into a camera, which records that), what allows to get a picture recording 30 frames per second. Research results were worked out by a computer program - ThermaGRAM95Pro. This software allows to achieve distribution of temperature onto a particular picture field or in a point of our special interest, or along determined line of measurement.

2.5. Heat parameters

In practice it is necessary to determine the heat time to realize operation of heat treatment. To achieve this aim empirical dependence can be used [3] (1):

$$\tau_n = \frac{t_p \cdot (1 - \sqrt{\frac{\Delta t}{t_p}}) \cdot Cp \cdot \gamma \cdot R}{E \cdot (\frac{T}{100})^4} \quad (1)$$

where:

τ_n - the heat time [hours], R - a roller thickness [mm], t_p – the furnace temperature [ºC], ΔT - difference between a furnace temperature and a target temperature, $\left(\frac{T}{100}\right)^4$ - Stefan-Boltzmana's equation element for a given furnace temperature, E – constant of radiation, C_p - a proper heat of cake, γ - a material density

The A temperature of cake heated for heat-rolling can be easily calculated using this relationship (1).

Accepting any of that assumptions equivalent for given furnace temperature and a kind of charge material, for instance: a cake from brass M66 with dimensions 140 mm x 700 mm x 7000 mm and a mass 6000 kg, arranged 19 cakes in one row, one after another, at a furnace temperature: tp = 850ºC (1123K), a specific heat Cp = 0.09 [kcal/kgK], a density d = 8600 [kg/m³], a constant of radiation E = 2.5 [kcal/m²hK].

Value of Stefan-Boltzmana equation element at 850ºC is accepted as 15*10³ K⁴) calculated heating time is 140 minutes.

2.6. Course of measurements

The order and character of performed research were presented in a Fig. 2. The most important objects, which exerted a resolute influence on a quality and technical - economic indicators of hot-rolling of copper and brass cakes.

The heating furnace

Thermovision investigations were performed on heating furnace body in order to discover so-called"heat losses' causing some energy losses and, as a consequence, heterogeneous temperature in a heating chamber of furnace and on surface of heating cakes. Some characteristic points of furnace for investigation were chosen (Fig. 3), i.e. surroundings of defined diffuser burners and side walls and some fragments of roof border of adjacent heating zones (1 and 2 as well as 3 and 4), which are responsible for keeping consistent temperature in a heating chamber.
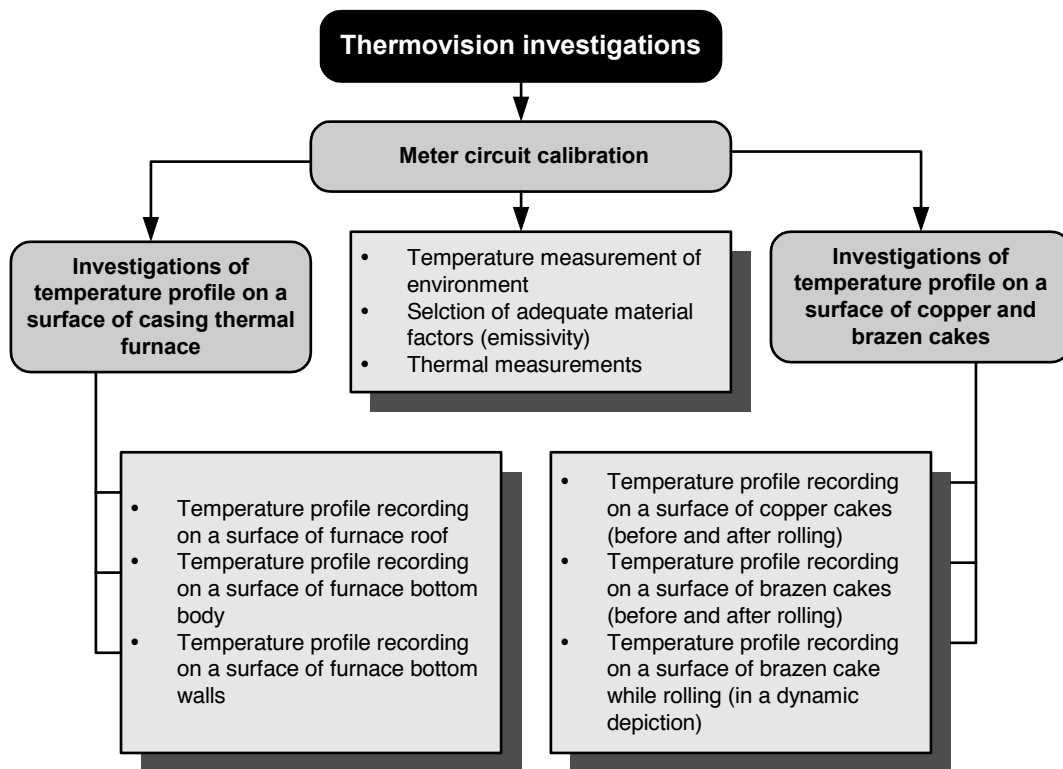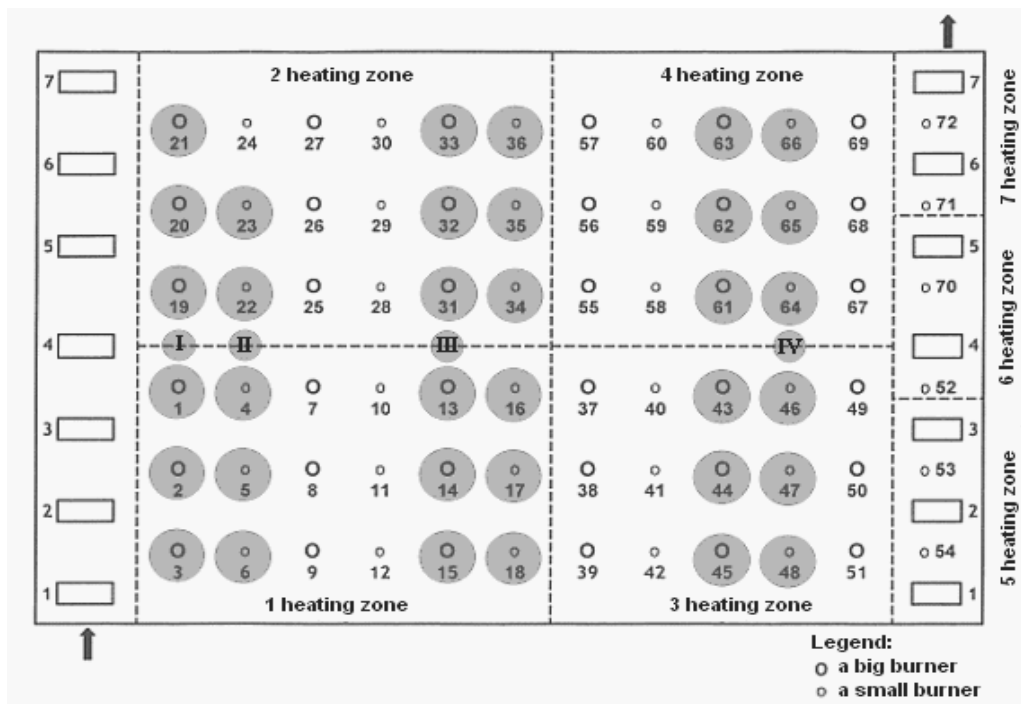
Fig. 2.The block diagram of the studies

Fig. 3. The furnace diagram with indicated points of temperature measurement

Copper and brass cakes

Investigations of temperature profile were performed on the surface of a heated cake to be rolled by a furnace roller conveyor operator and on input roller track going to a rolling mill as well as in a hot-rolling process on both sides of the rolling mill roller tracks, i.e. on even and uneven roll passes.

Environment conditions and material parameters

An important aspect of thermovision measurements is a suitable match of some emissivity parameters of tested materials, because obtaining correct results depend on them. In connection with this, before measurements were taken, essential structural features of testing objects and these data were taken into account in settings of a thermovision system. Taking into account surrounding conditions, in which studies were made i.e.: air temperature, humidity, presence of water vapour, and in relation to structure elements – occurrence of oil spots, dust, paint layers and other impurities, it was needed to determine a temperature in points, where surface emissivity could have been changed or misread. These points were tested with the help of a thermocouple, what allowed in a unique way to verify their temperature. The results of these measurements and parameters connected with the environment, determined a reference point to calibrate the thermovision system.

3. Description of the achieved studies

Thermal furnace

While studying the ambient temperature was about 20ºC, but in the thermal chamber of furnace, it was 92°C. First analysis of temperature profile on furnace body was performed on its roof. The sequence of research was consistent with the earlier determined diagram (Fig. 3). Demonstrative results of the research were presented in a thermogram form in Figs. 4 and 5. The next stage of furnace body research was to determine a temperature profile on the walking beam furnace bottom under the following heating zones. Demonstrative results of point research are determined in Fig. 6, presenting a thermogram performed in Fig. 7. The final stage of furnace body research is temperature profile ripening on side walls. The performed results (in determined place in 8), were presented in thermogram no 9.

Fig. 5. The furnace roof, surroundings of burner diffuser no 2

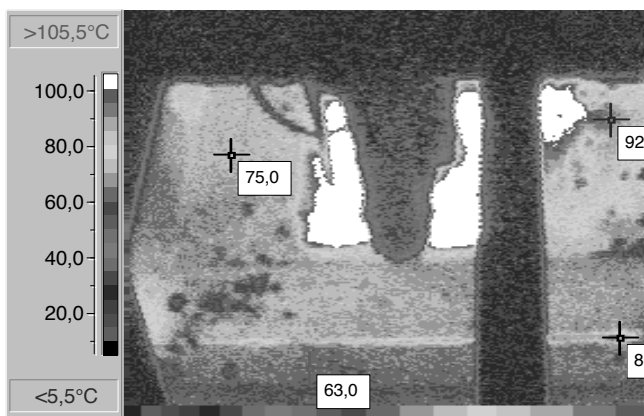Fig. 6. The actual picture of testing area from a viewpoint of the following heating zones

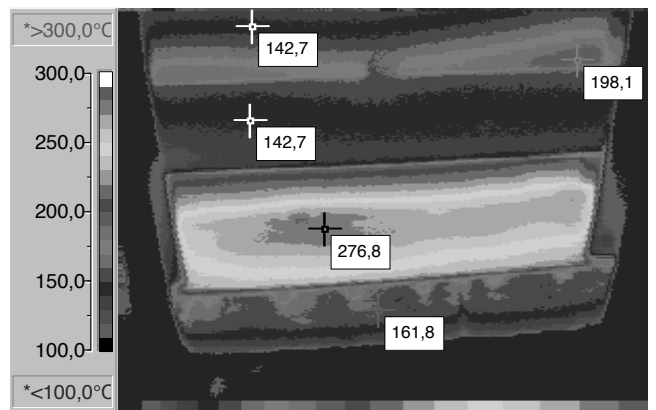Fig. 4. The furnace roof, surroundings of burner diffuser no 3

Fig. 7. The furnace bottom, the second segment, area under the third heating zone

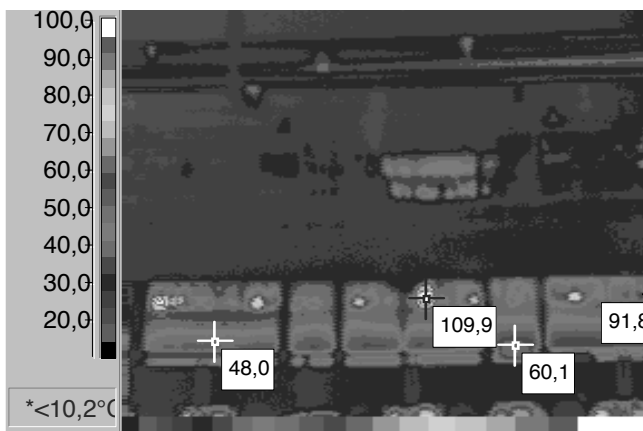Fig. 8. Actual picture of the front furnace body

Table 2.
Temperature profile on cakes surface

No	No of cake	Material	Temperature range [ºC]
1	99 857	M63	720 - 660
7	99 771	M63	750 - 680
8	99 865	M63	740 - 690
9	99 864	M63	740 - 700
10	99 851	M63	750 - 700
13	99 808	M67	780 - 750
14	99 804	M67	770 - 730
15	99 838	M67	760 - 730
16	99 806	M67	770 - 730
22	99 841	M67	750 - 690
24	99 897	M70	770 - 720
25	99 889	M70	780 - 730
26	99 887	M70	780 - 730
29	99 872	M70	770 - 730
30	99 904	M70	790 - 730

Fig. 9. The temperature profiles on the lateral furnace wall, as seen from a mill roller table
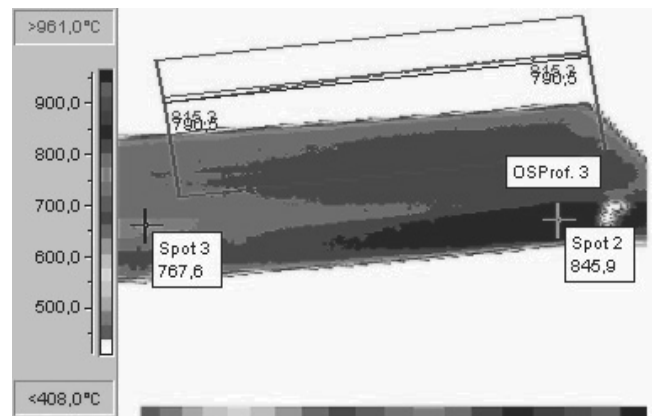
Fig. 10. Hypothetical temperature profile on an cake M2R front of cake (a head) - first cake

Copper and brass cakes

Temperature profiles on surfaces of heating brass cakes recorded by furnace pyrometer presented in Table 2. However, hypothetical investigation results of temperature profile on brass cakes in a M2R, after leaving a thermal chamber of furnace, placed on a mill roller table, before the first roll pass, are included in Figs. 10 and 11. Figs. 12 and 13 present thermovision images of copper cakes, after following roll passes. Some demonstrative thermovision pictures of brass cakes in a M63 in Figs. 14 and 15 were presented. The last stage of thermovision measurements of hot-rolled cakes were investigations of temperature profile on the surface of the rolling cakes (strip) in a dynamic depiction. These investigations include a temperature profile all the down the rolled strip, following the roll passes. This investigation was to determine a point on the cake surface and sampling a temperature from this place in defined intervals of time with each subsequent roll pass. The list of investigation results was shown in a form of diagram in Fig. 16.

Fig. 11. Hypothetical temperature profile on an cake M2R central part of cake – first cake

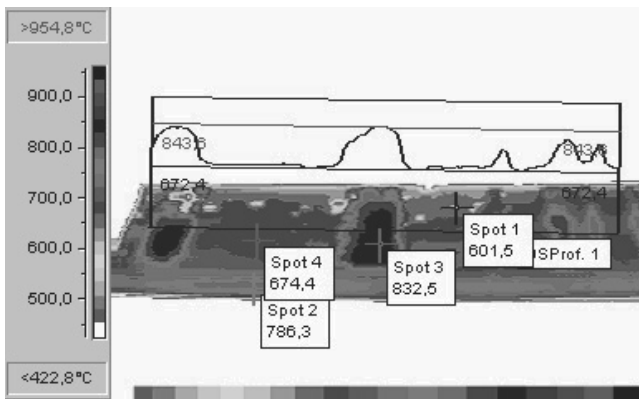Z. Rdzawski, B. Krupińska, M. Musztyfaga

Fig. 12. Temperature profile on a surface of a rolled cake, after a first roll pass, central part of cake (an M2R, no 24552) water cooling
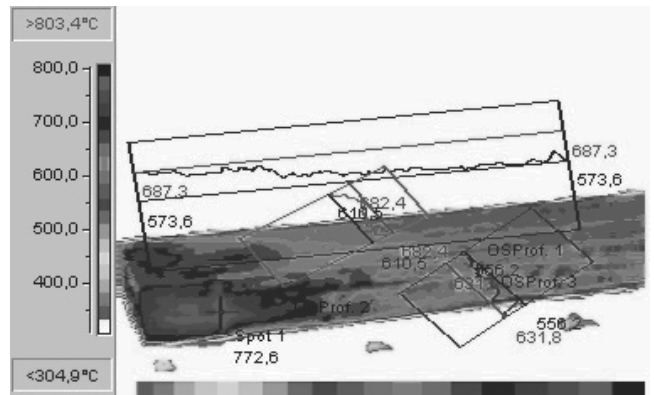

Fig. 14. Temperature profile on a cake surface M63 (no 99771) before rolling, the final part of cake (a tail)
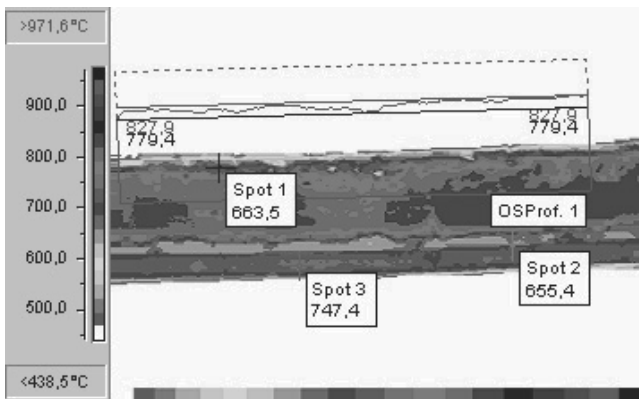

Fig. 13. Temperature profile on a surface of rolled cake, after the second roll pass, central part of cake (an M2R, no 24630)
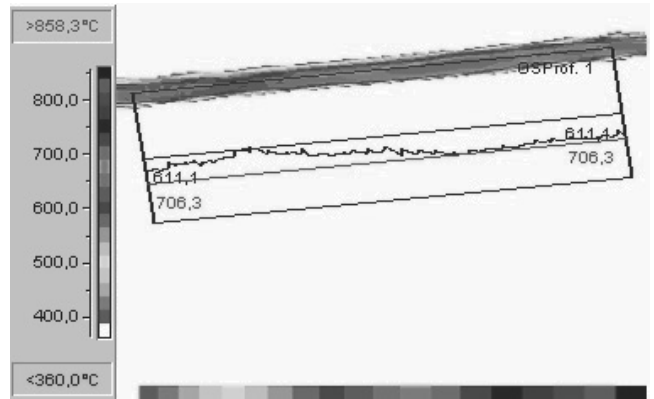

Fig. 15. Temperature profile on lateral surface of rolling cake, after the fourth roll pass (M63 cake, no 99771)

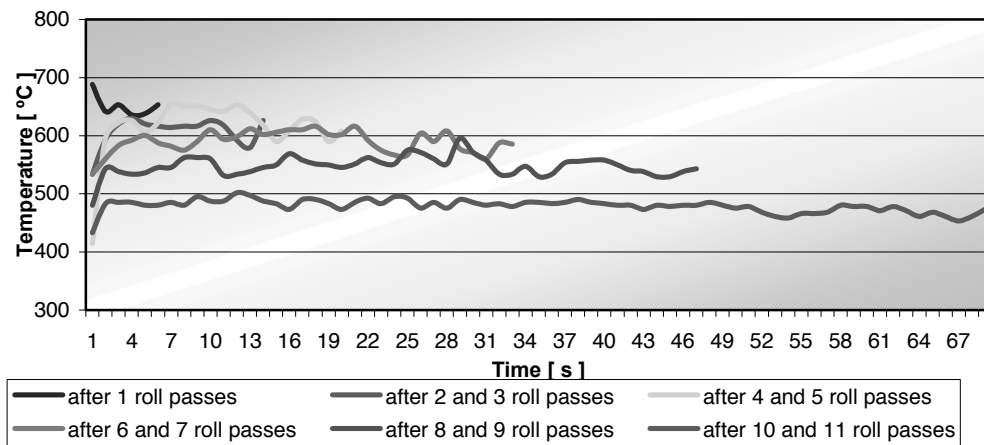**Temperature profile on a rolled band M70, after following roll passes**

Fig. 16. The temperature profile in the following roll passes in a dynamic depiction

3.1. Results and discussion

Heat furnace

Studies performed on the walking beam furnace were divided into 3 stages i.e. roof, furnace bottom body and side walls. Recorded temperature profile on a furnace roof, allows to ensure that the average temperature on the surface is about 80ºC (Fig. 17). The points located in thermograms are characterized by considerable higher temperatures, which determine surroundings of burners diffusers. Higher temperatures in the lower points are caused by the construction of these elements – in a shape of funnel.

The only point of a significant heat loss, caused by another reason rather than previously described – surrounding of burner diffuser placed in a row no 2 in the centre of the furnace, is presented in Fig. 3. In this point, heat barrier was probably damaged.

The temperature profile on furnace bottom body is characterized by sufficient equality, however the temperature of furnace constructional elements in comparison with its roof is much higher, and on average is equal 150ºC in 1 and 3 heating zone environs (furnace refractory), and 100ºC in 2 and 4 heating zone environs (furnace refractory). Maximum temperatures on outer body of furnace bottom appears on steel elements, what is caused by better thermal conductivity in comparison with the furnace refractory. The structure of the highest temperature on steel elements from this part of furnace body is presented in Figure 18. At this stage of research no significant heat losses, caused by damages or worn elements of furnace body were observed.

Research carried out on side walls, do not show any points of particular raise of surface temperature, and following considerable heat loss. The average recorded temperature on these body elements is about 60ºC (Fig. 19).

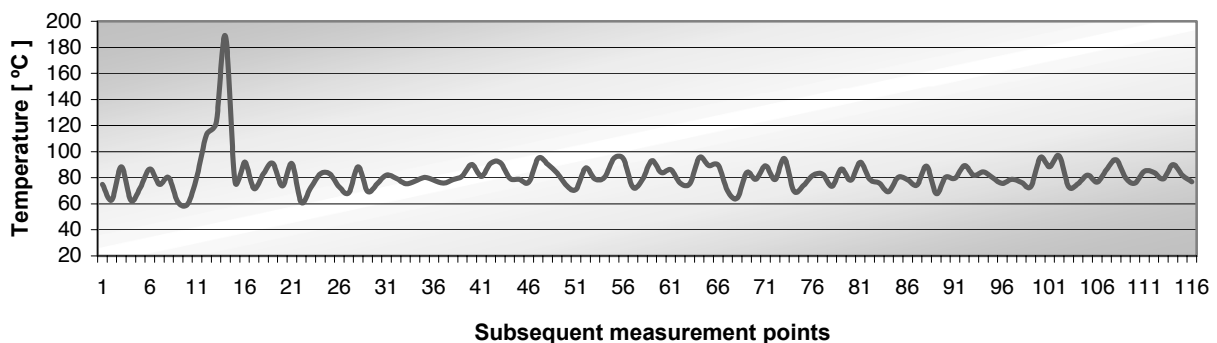**Cumulative temperature profile on heat furnace roof**

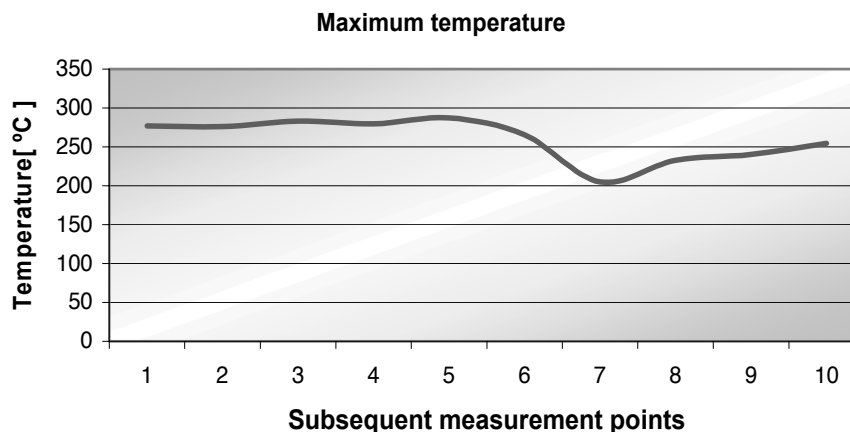Fig. 17. Results of temperature measurement on the furnace roof

Maximum temperature

Fig. 18. Maximum temperature measurements on the body of furnace bottom in points of thermovision measurements

Cumulative temperatures distribution on side walls of heat furnace body
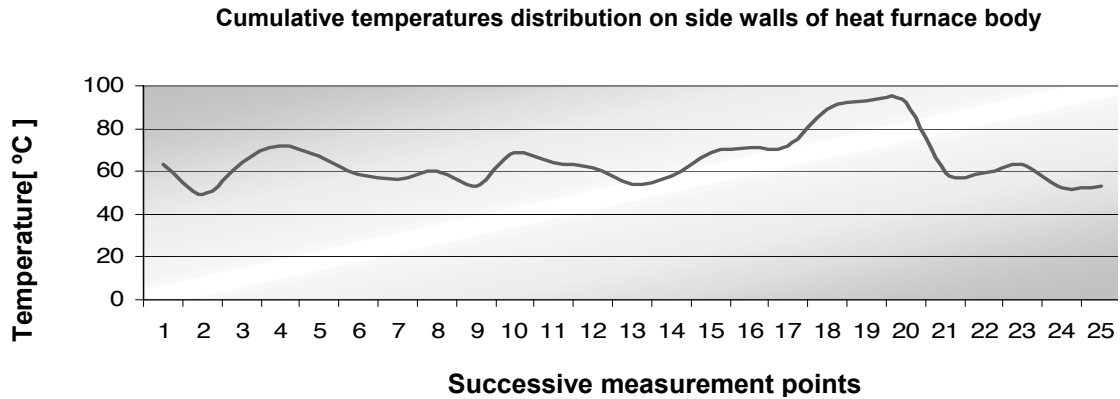

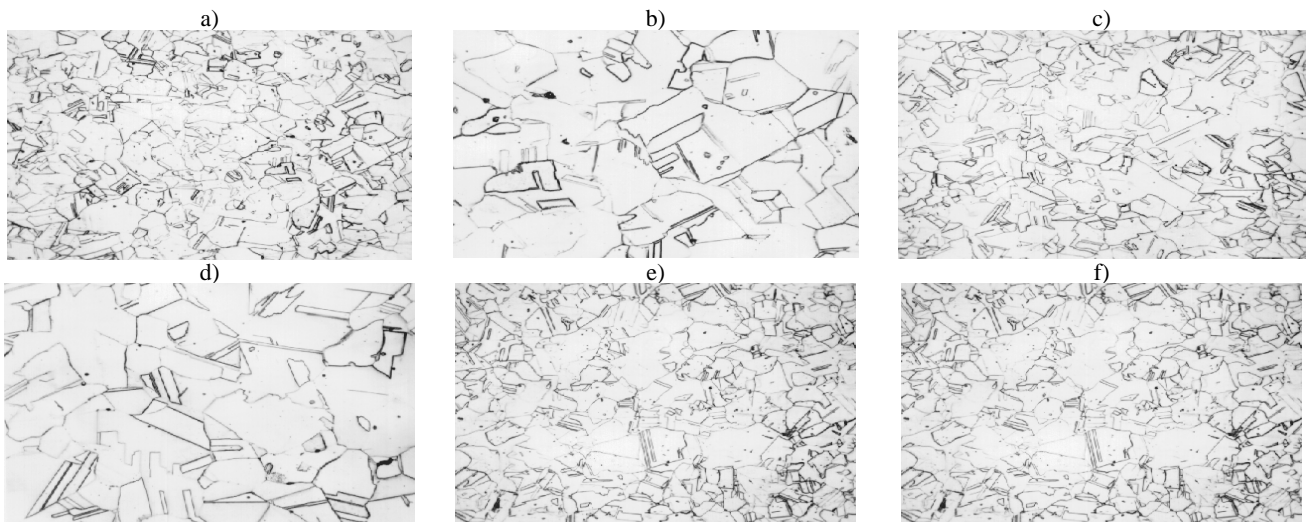Fig. 19. Results statement of temperature measurement on side walls of furnace body

Fig. 20. Microstructure image of cooper M2R, post hot-rolled – samples taken from a head of strip (a (120x), b (300x) - a left side of strip, c (120x), d (300x) - a central strip, e (120x), f (300x) –a right side of strip)

The temperature profile on body of the heat furnace allows to identify that a thermal condition is good, it does not demand revamping (except for checking and potential repairs on furnace roof and improvement of insulation in surrounding of furnace door) and it does not cause heat losses. This condition of the walking beam furnace body allows for optimal cakes heating, consisting in elaborated heating according to developed heating programs.

Copper and brass cakes

The thermovision investigations of cakes were divided into 2 stages, i.e.: investigations of temperature profile on cakes surface and cooper and brazen strips. The first cakes thermovision images of a M2R showed a huge heterogeneity of temperature profile on a surface, reaching even 200 ℃ between particular elements of cakes (Figs. 10 and 11). Occurrence of these kind of differences, has its own technological justification, because it always takes place, after longer heat furnace and a rolling mill downtime and a change of workable material from copper to brass and inversely. This problem can be solved applying extended time for heating by about 30 minutes, what allows to compensate temperature on the surface of cakes. The temperature profiles on a hot-rolled materials in even and uneven roll passes were uniform, thus only disturbance points were caused by cooling water evaporation (especially shown in a Fig. 12). While conducting a technological hot-rolled process, the correct temperature profile assures obtaining homogenous structure on a rolled copper strip (Fig. 20).

Dynamical research performed for a cake made of M70 (Fig. 16) are characterized by temperature profiles on rolled strip, following roll passes. They indicate a uniform heating of cake and the formed differences were caused to a large extent, by evaporation of cooling water. Lines defining roll passes show a stable characteristic (a lower temperature at the beginning and at the final roll pass, higher in the centre), what is consistent with theoretical assumptions (heat exchange with the environment). The line defining only a temperature profile for the first roll pass shows a decreasing tendency.

4. Conclusions

We can obtain some beneficial set of mechanical properties, with keeping up adequate technological parameters of heating process and hot-rolling for brass in a M66 grade, for instance [10]:

Beginning of strip:

- R_m in ranges   from 339.7 to 344.2 MPa
- R0.2 in ranges   from 131.1 to 143.5 MPa
- A5 in ranges   from 60.7 to 64.6 %
- HV in ranges   from 95.6 to 112.7

End of strip:

- Rm in ranges   from 342.8 to 349.9 MPa
- R0.2 in ranges   from 136.0 to 156.6 MPa
- A5 in ranges   from 57.9 to 64.0 %
- HV in ranges   from 93.6 to 118.4

Comparing medium values of these properties from the beginning to the end of the strip (Table 3), we can say that they differ from themselves insignificantly.

Table 3.
Comparison of average values R_m, $R_{0.2}$, A_5, HV of the beginning and the end of the strip

	Strip beginning	Strip end
R_m [MPa]	341.3	345.0
$R_{0.2}$ [MPa]	137.8	141.1
A_5 [%]	63.0	61.4
HV	104.4	107.9

Standard deviation of mechanical properties can be any homogeneity measurement for these properties (Table 4).

Table 4.
Standard deviation of mean values R_m, $R_{0.2}$, A_5, HV beginning and the end of the strip

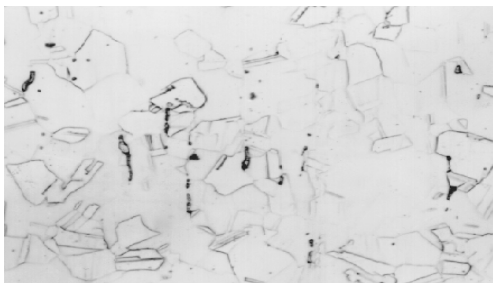|	Strip beginning	Strip end
R_m [MPa]	1.2	2.0
$R_{0.2}$ [MPa]	3.5	4.3
A_5 [%]	1.1	1.6
HV	4.0	6.4

Fig. 21. Image of strip microstructure made of M66 alloy, after hot-rolling (300x). Perpendicular microsection in a rolling direction. The beginning of strip

The microstructure of the blank characterises a good homogeneity along and across the strip. Hence, in Figs. 21 and 22 only hypothetical microstructure images were presented from a centre of the strip.
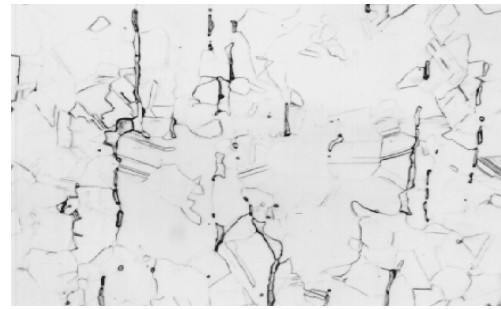

Fig. 22. Image of strip microstructure made of M66 alloy, after hot-rolling. Perpendicular microsection in a rolling direction. The end of strip

As it resulted from inserted microstructure images in a strip, once hot-rolled the second phase occurs in not large amounts. On the basis of performed, detailed research using roentgen micro-analyzer it was pointed out that this is β phase with Cu content = 53.29 % mass and Zn= 46.71% mass. While they adhered into this phase, the chemical composition of matrix α was the following: Cu = 64.45 % and Zn = 35.55 %. Qualitative results of these studies illustrate respectively Figs. 23 and 24. Fig. 25 presents a hypothetical image of orientation schedule after it is hot-rolled. On the entire width of the strip from its beginning to the end, the whole crystalline microstructure at average diameter of 0.050 mm has flat grains.

The material of these properties and microstructure is optimal, initial material for further processing in initial cold-rolling.
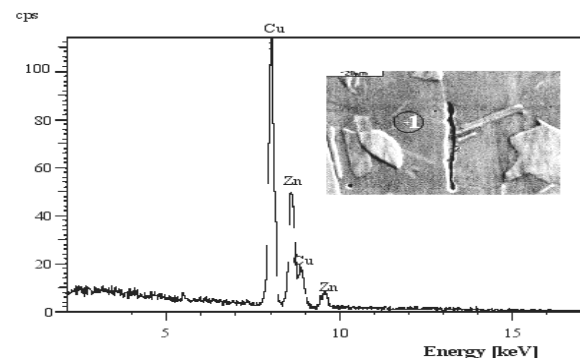

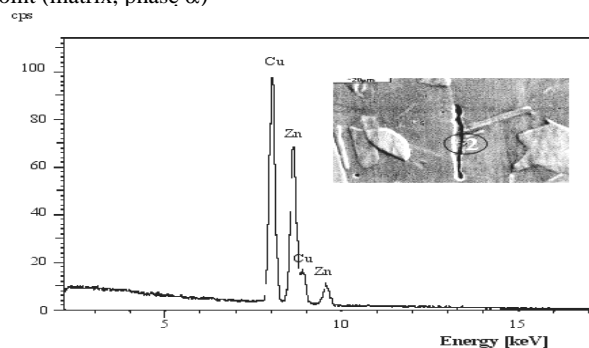Fig. 23. Spectrum of energy-dispersive M66 brass from the first point (matrix, phase α)

Fig. 24. Spectrum of energy-dispersive M66 brass from the second point (phase α)
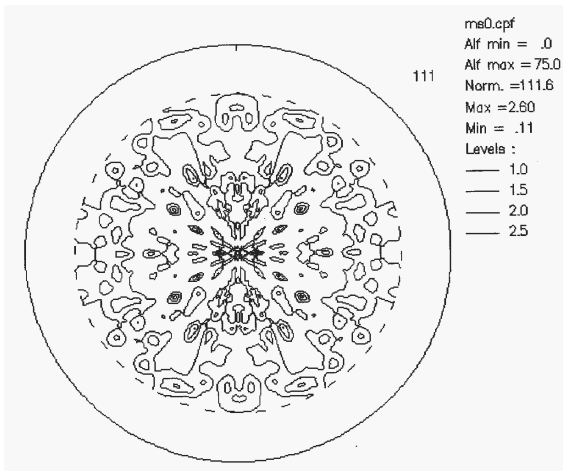
Fig. 25. Image of brass schedule orientation M66, after hot-rolling

The condition of furnace body allows for optimal cakes heating, and thank to this transition to the rolled cakes, no differences will be found in material structure, and they will proceed uniformly at the whole intersection. Thermovision measurements used to evaluate heating processes of hot-rolled cakes present a necessity of systematic controls: a condition of the heat furnace, what will allow to avoid defective products and to minimize costs of possible repairs; cakes functioning while rolling in order to find any possible structure defects and adequate temperature profile, which significantly influences on efficiency of the conducted process and lifetime of the rolling mill.

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