Andrzej Drotlew[*], Bogdan Piekarski[*], Joanna Tuleja[**]
[*] Szczecin University of Technology, Department of Materials Engineering, Szczecin, Poland
[**] Maritime University of Szczecin, Department of Transport Engineering, Szczecin, Poland

WEAR AND TEAR OF CHARGE-CARRYING ELEMENTS IN CARBURISING FURNACE

ABSTRACT

The present study discusses the problem of degradation of cast elements carrying charge in carburising furnaces. The wear and tear of castings, which finally results in decohesion of walls, is due to an effect of the carburising atmosphere and thermal fatigue.

Key words: *thermal fatigue, carburising, failure, austenitic cast steel*

INTRODUCTION

Various accessories used to carry and transport the batches of charge in carburising furnaces (the charge-carrying elements) are mainly produced from austenitic cast steel. The conditions of their performance are directly defined by temperature variations during carburising and quenching of steel parts (Fig. 1).

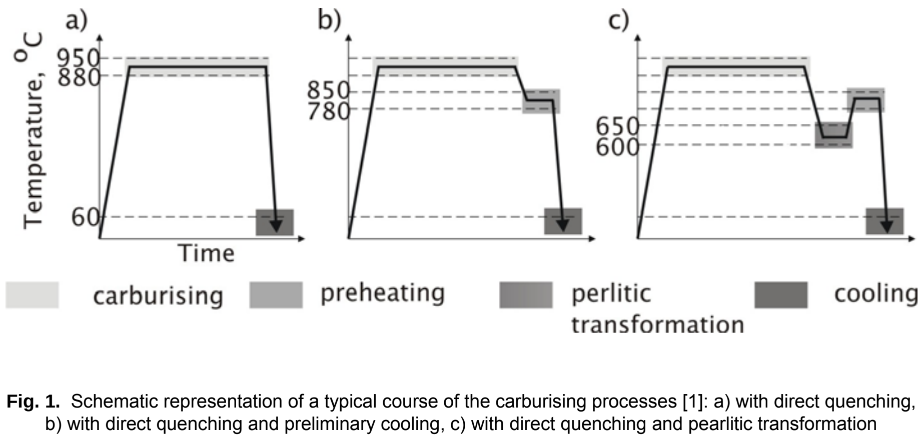


Fig. 1. Schematic representation of a typical course of the carburising processes [1]: a) with direct quenching, b) with direct quenching and preliminary cooling, c) with direct quenching and pearlitic transformation

The performance life of the charge-carrying elements decides about the reliability, and hence, about the operating cost of a carburising furnace [1÷3]. Basing on the results of an analysis of the operating conditions, three groups of interrelated processes deciding about the wear and tear of these elements have been indicated [1÷4]:

- high temperature corrosion, mainly carburising,
- thermal fatigue due to rapid heating and cooling of the charge,
- creep due to static loads, i.e. the weight of the charge and own weight.

This study gives the results of an analysis of the damages suffered by charge-carrying elements operating in chamber and pusher-type carburising furnaces. The analysis was made basing on visual assessment of the scrap.

EXAMPLES OF FAILURE OF THE CHARGE-CARRYING CAST ELEMENTS AND CAUSES OF THEIR FAILURE

The main charge-carrying element is a thin-walled openwork grate usually made from creep-resistant 36%Ni-17%Cr cast steel [1÷3]. It plays the role of a pedestal on which one can:

1. Place a fixture holding inside the parts to be carburised (Fig. 2a).
2. Construct by means of auxiliary grates and supporting rods a structure which enables stable fixing of parts to be carburised (Fig. 3a).

On performance, the charge-carrying elements are exposed to heavy thermal shocks which, during cyclic operation, lead to damages caused by thermal fatigue. The fields of own stresses formed in castings are caused by temperature gradient which occurs in external and internal areas and on the cross-section of a single wall. An immediate effect of the thermal fatigue is deformation and cracks formed in the walls (Fig. 2b) and, at the final stage of degradation, local or total decohesion of casting (Fig. 2c). Due to this, the grate has to be withdrawn from use before its structure breaks down completely, otherwise a seizure may occur, followed by failure in furnace operation and rejection of the carburised parts [2].

The operating regime of the charge-carrying elements is generally recognised as extremely hard. To create for these elements the conditions which would enable an unrestrained change of dimensions (under cyclic changes of temperature) may prove to be very difficult in practice, or possible to some limited extent only. This well show some examples of the damages occurring in castings, caused by either complete or partial constraints in free deformation of a single element or mate elements [5,6]. So, the use of irrational designs may cause destruction of castings even during the first few cycles of operation [2]. The design, which is a typical example of misunderstanding how the problems related with structure resistance to thermal fatigue are functioning, is joining of casting walls by an „X" node – (Fig. 2b-1). It can be assumed with great probability that the „thick" structure formed by a node like this will favour as early as at the stage of casting solidification the formation of microcracks in this region.

The shocks of purely thermal nature affecting the casting are further aggravated by the aggressive effect of carburising atmosphere. The carburised layer formed in the sub-surface region of castings (Fig. 2c-2) is characterised by the mechanical and physical properties definitely inferior in respect of the non-carburised core [6÷8].

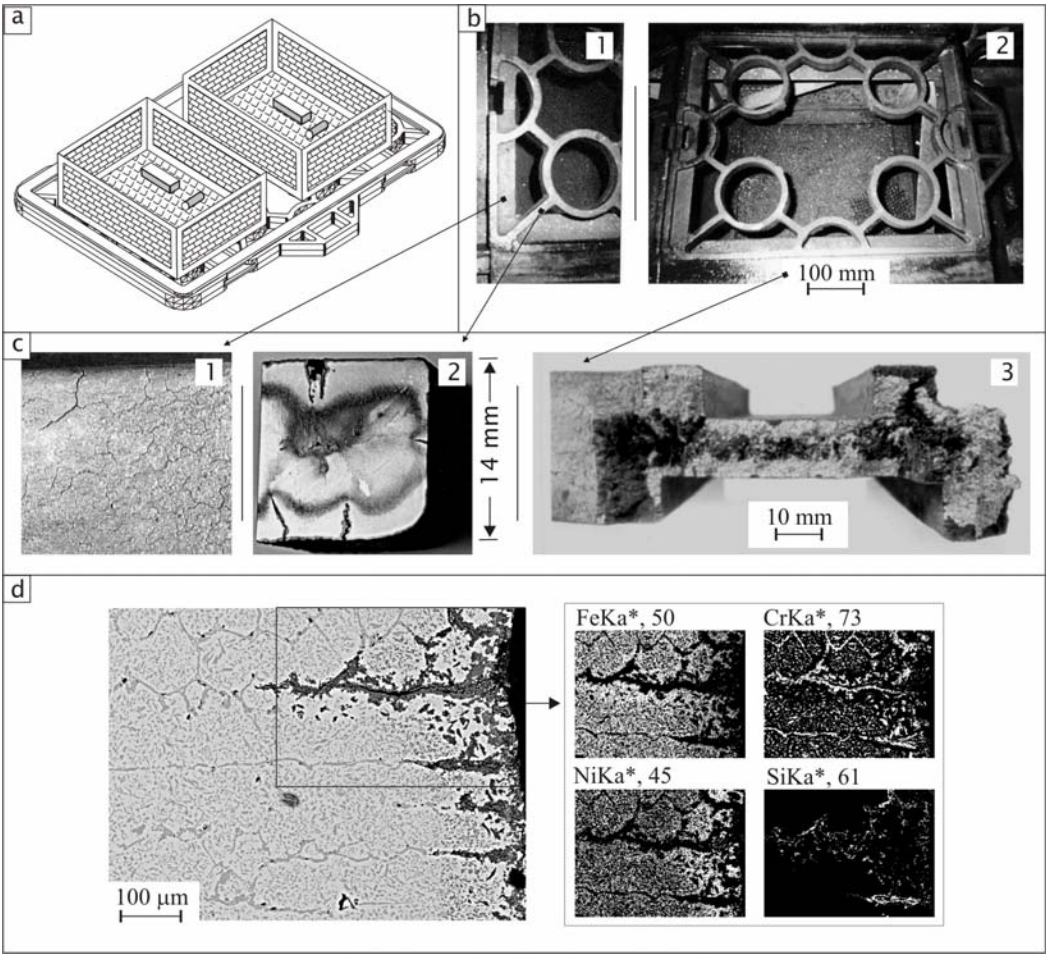


Fig. 2. The grate from a carburising chamber furnace withdrawn from use [2]: a) schematic diagram, b) cracks and deformation of walls (1), scrap grate (2), c) surface cracks (1), macrostructure of the wall cross-section (2) with well visible carburised layer, cracks and axial porosity, fracture (3) with well visible internal casting defects, d) microstructure of sub-surface layer and distribution of Fe, Cr, Ni, Si on the surface around cracks

In general terms it can be stated that the process of carburising proceeds at a higher rate, when casting is subjected to a cyclic effect of rapidly changing temperatures, and vice versa. Under the conditions of the carburising atmosphere, the resistance of casting to thermal shocks rapidly decreases. At the same time, because of the forming cracks, the inside part of the casting also gets carburised. Carbon penetrating from the atmosphere reaches through cracks also the axial porosities (Fig. 2c-2). Summing up of these effects causes much greater corrosion damage to the cast material than it would have happened if these adverse effects had been acting separately. Under these conditions, even after a few hundred hours of the casting operation, its surface is losing heat-resistant properties, becomes brittle and cannot resist the internal oxidation (Fig. 2d), while the initially very good utilisation properties of cast steel suffer rapid degradation (Table 1). Additionally, the carburised layer characterise lower, in respect of the non-carburised core material, value of the coefficient of linear expansion α which, during the process of preheating, causes the formation of high tensile stresses favouring the nucleation and propagation of fatigue cracks.

Table 1. *Properties of the base grate cast made of 0.35%C-36%Ni-17%Cr steel [8]*

Casting*/	R_e MPa	R_m MPa	A_{10} %	KU J/cm^2	HB	α × 10^{-6} deg^{-1}
1. Unused	285	511	30	78,2	162	14,3
2. After performance	–	501	0	6,4	269	11,7

*/ specimens for tests were taken from castings

The process of degradation of the grate assemblies is much more complex than it is in the case of one single grate. The decohesion in the corners of a lower (base) grate (Fig. 3-1) and in an upper - intermediate grate (Fig. 3-2) is the result of external bounds, i.e. of the reaction of constraints. Variations in mass and in the wall cross-sections are the reason why the time of their heating/cooling is different. From the point of view of the resistance to thermal fatigue, very disadvantageous are the differences in shape and mass between the base grate and the intermediate grate. This is not only because of the function they are expected to perform but also because of the economic reasons - the weight of the accessories should be reduced to minimum in respect of the weight of the carburised charge. The intermediate grates with walls usually thinner get heated/cooled in a time much shorter than the base grate. During of the charge preheating process, the supporting rods joining them are bent to the outside, and during cooling to the inside. Since these operations are repeated in regular cycles, the result is, on one hand, breaking out of the corners, and on the other - the deformation of rods (Fig. 3).

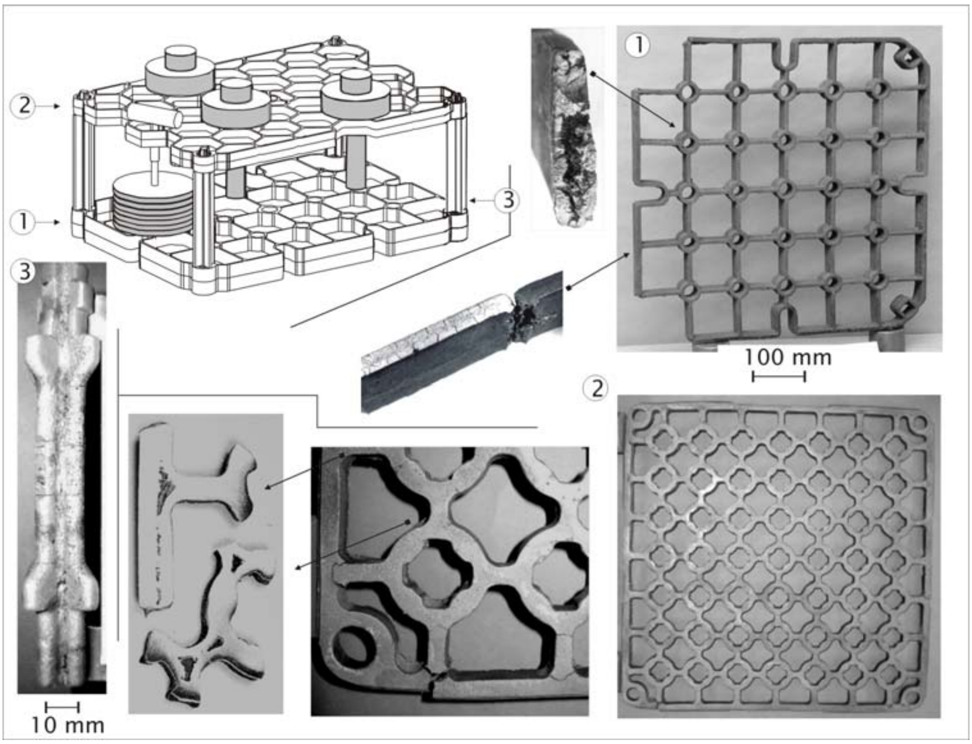


Fig. 3. An assembly of grates withdrawn from use in pusher-type furnace [4, 5]: 1) scrap base grate, internal defect located in hot spot and cracks in rib, 2) scrap intermediate (upper) grate, through cracks and shrinkage cavities in „T" type nodes, 3) supporting rod with cracks and deformation

The next factors speeding up the degradation of castings are external and internal casting defects. External defects accelerate the process of carburising and crack formation (Fig. 2c-2). Therefore defects of this type should be eliminated as early as during the stage of making the casting. The presence of internal defects is impossible to be avoided, although there are designs and engineering solutions [6,9] which at least enable mitigating the severity of their occurrence and reducing the area they occupy. The openwork structure of the grates is the reason why it is not possible to avoid extra layers of material on wall joints. These extra layers play the role of hot spots in which the defects, like shrinkage cavities and/or shrinkage porosities are located most often (Fig. 2c-2,3 and Fig. 3). This not only reduces the functional wall cross-section but also, as proved in [8], can give rise to the nucleation of cracks running inside the wall in direction from the surface of the defect.

Here it is worth noting that among the direct causes of casting degradation no failures resulting from the static loading by charge have been observed to take place [4÷6,8].

EXAMPLE OF ANALYSIS OF THE MECHANISM OF GRATE DEFORMATION AND BREAKING

The deformation of corners is the deformation often observed in grates. „Swelling" of corners outside the grate outer band contour can go from a few up to even twenty millimetres (Fig. 4a). Deformations of this type are specially dangerous when the grates are working in a pusher-type furnace in which they should hold a stricly determined position in view of the fact that they are cooperating with a push-through device and with other grates. Additionally, summing up of deformations present in individual grates along the length of the furnace chamber makes their correct functioning impossible [8].

The charge should be placed on grates in a way such that the outer grate band contour is extending outside of the charge (Figs. 2, 3). This is the reason why in the studies of the grate behaviour on heating and/or cooling it is necessary to divide conventionally the grate into two zones (Fig. 4b). The first zone will be the middle part of the grate covered by the charge to be carburised. The instantaneous distribution of temperatures in this zone will be vitally affected by the size and shape of the carburised parts. The second zone is a band forming the grate contour. It can be assumed that the temperature distribution found in this zone at a given time instant is independent of the charge.

On performance, the thermal stresses are formed even in the part of the grate which is not burdened with charge. These can be, as mentioned previously, the stresses related with temperature gradient occurring on the cross-section of single walls and stresses due to the rate of heat transfer higher in the band forming grate contour than in the middle part. The difference in the rate of temperature changes between the middle part and the outer band will become more prominent even when the grates are burdened with charge.

Basing on the results of an analysis of changes in the shape and dimensions of several types of the grates withdrawn from use [7,9], a model explaining the mechanism of the grate corners deformation was proposed. The best procedure is to make analysis on a skeleton model of a fragment of the grate, examining changes in its shape at the successive stages of rapid preheating and cooling (Fig. 4c).

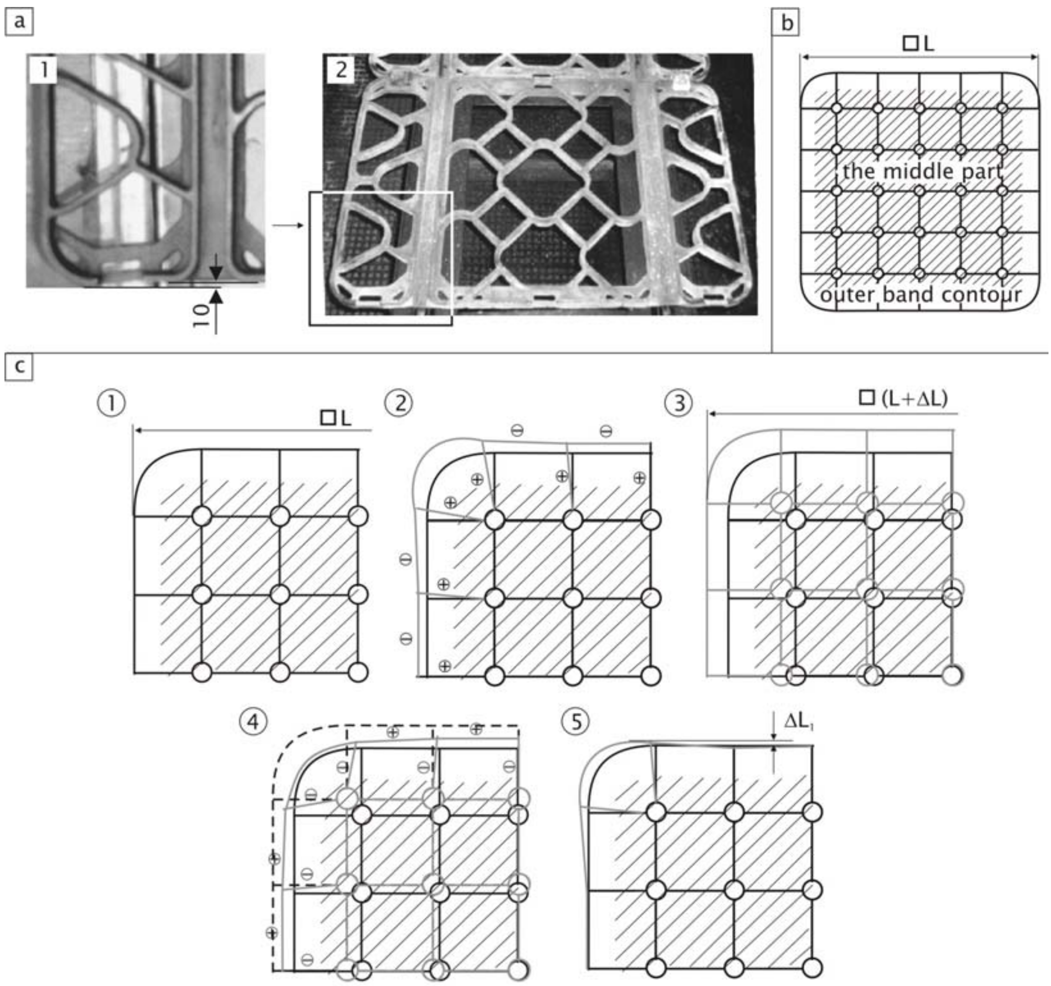
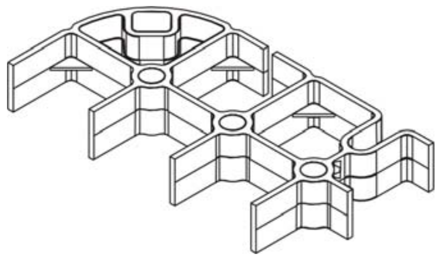


Fig. 4. Deformation of grate corners [10]: a) grate withdrawn from use: 1 – deformation on the corner, 2 – general view, b) conventional division of grate into the middle part burdened with charge and outer band contour, c) the cycle of changes in dimensions to which the grate is exposed during temperature variations: 1) initial condition, 2) the condition during rapid preheating; the instantaneous temperatures in outer band contour are higher than in the middle part, 3) the stable condition after preheating to process temperature, 4) the condition during rapid cooling; the instantaneous temperatures in outer band contour are lower than in the middle part, 5) stable condition at ambient temperature; deformation of grate corner

A quarter of the grate in initial condition, that is, at ambient temperature, is shown in Figure 4c-1. When the grate with charge is placed in a preheated chamber of the furnace (Fig. 4c-2), there is a rapid heat transfer in the outer band and much slower in the middle part of the grate. Finally, an instant comes when during the heat transfer process the band of the grate has the temperature much higher than the part covered by the charge. As a consequence of this state, the linear dimensions of the grate will increase in respect of the initial state, and the effect of this elongation will sum up within the area of the corners. The outer band will be affected by the compressive stresses, while middle part of the grate will suffer the effect of the tensile stresses. The parts most exposed to the effect of permanent deformations will be the ribs, directly adjacent to the outer band within the area of the corners, because in this place the heat transfer, due to the interposing heat fluxes coming from different directions, will be the most rapid. When the proof stress is exceeded, the ribs will undergo a permanent elongation. Upon the temperature of carburising having been reached, the temperature in all parts of the grate will get stabilised, and the dimensions of the band will increase by the value of ΔL (Fig. 4c-3) (to make the analysis simpler, possible increase in the length of the internal ribs in the area of the corners, caused by their individual heating and the related state of stresses, has not been taken into consideration). During rapid cooling, the changes will proceed most quickly again in the external band (Fig. 4c-4). Because of its reduced linear dimensions, the grate perimeter will be „squeezing" the middle part. This will cause the formation of tensile stresses in the external band and of compressive stresses in the middle part of the grate. The consequence may be permanent increase in the length of the „stretching" elements of the grate outer band. After cooling to ambient temperature, the dimensions of the outer band contour will be larger than those of the ribs located in the middle part of the grate. The summing up of deformations occurs in the end part of the grate, and therefore the consequence will be pushing out of corners beyond the original contour. After the sufficiently long time of the grate performance it can be expected that the deformation of its corners will be permanent (Fig. 4c-5).

The deformation of the grate corners can be avoided through application of proper design (Fig. 5).

Fig. 5. Changes in grate design reducing in its outer band the tendency to deformation of corners and crack formation on wall joints [6]



The displacement of the outer band can be mitigated through application of the following solutions: slits in the outer band, „U" type stress relieving bends, and reinforcing ribs. The application of those means, jointly or separately, depends on the specific needs, and in majority of the cases brings the expected results [5]. The next step in improving the design of the grates should be the development of such designs which would during changes of the operating temperature ensure that the deformation in the outer grate band is „pushed" to the inside of the grate and not as up to now to the outside.

SUMMARY

From the above described process of degradation of the charge-carrying elements three general conclusions follow, and they define the procedure which should be followed in order to increase the life of the charge-carrying elements:

1. Since it is impossible to totally eliminate the process of casting carburising, of an utmost importance for the life on performance of this casting will be improving the cast steel resistance to thermal fatigue under the conditions of an effect of the carburising atmosphere.

2. In the process of degradation of the charge-carrying elements very important role is played by the thermal fatigue behaviour under the conditions of both external as well as internal constraints, because the fields of own stresses forming in castings originate from factors present in these two groups. The presence of casting defects both on the surface and inside the casting accelerates the thermal fatigue and carburising processes.
3. No permanent deformations have been observed to occur in castings due to the creep effect. The examined examples of the grate degradation show that neither the static (bending) loads caused by the charge, nor the creep effect can be regarded as an immediate reason of the grate deformation and failure.

REFERENCES

1. Moszczyński A., *Nawęglanie gazowe stali*, WNT, Warszawa 1983.
2. Grzyb J., Trzciałkowski J., *Urządzenia do obróbki cieplnej w atmosferach regulowanych*, WNT, Warszawa 1975.
3. Lai G. Y., *Heat-Resistant Materials for Furnace Parts, Trays, and Fixtures,* ASM Handbook – Heat Treating, 1991, vol. 4, p. 510.
4. Piekarski B., *Makrostrukturalne aspekty zużycia odlewów palet stosowanych w piecach do nawęglania,* Archiwum TMiA, Poznań 2000, Vol. 1, p. 45.
5. Drotlew A., Piekarski B., *Oprzyrządowanie technologiczne do pieców do obróbki cieplno-chemicznej. Projektowanie i eksploatacja,* Szczecin 1998 (niepublikowana).
6. Piekarski B., *Odlewy ze staliwa austenitycznego w budowie pieców do nawęglania – teoretyczne i praktyczne aspekty podwyższania trwałości*, Prac. Nauk. Polit. Szczecińskiej, Szczecin 2003, nr 573.
7. Grabke H. J., Wolf L., *Carburization and Oxidation,* Mater. Sc. Eng., 87, 1987, p. 23.
8. Gutowski P., Piekarski B., *Analiza przyczyn niszczenia palet do pieców do obróbki cieplno-chemicznej*, Prac. Nauk. Polit. Szczecińskiej, Szczecin 1985, nr 281, p. 33.
9. Steinkusch W., *Hitzebeständiger Stahlguss für Wärmebehandlungsanlagen,* Gas Wärme Inter., 6, 1987, p. 340.
10. Drotlew A., Piekarski B., *Żarowytrzymałe odlewy palet – uwagi konstrukcyjne i technologiczne*, Arch. Odlew., 1, 2001, p. 446.