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INNOVATED CONSTRUCTION OF TUNDISH COVER WITH INCREASED SERVICE DURABILITY

INNOWACYJNA KONSTRUKCJA POKRYWY KADZI POŚREDNIEJ COS O PODWYŻSZONYM CZASOOKRESIE PRACY

In this study a new concept of the cover for installation for continuous casting of steel have been studied and discussed. The main essence in the most favourable construction includes the existing stresses and strains developed in service conditions. Instead of former cover, made with heat-resistant concrete and flat plate, the new solution introduced two factors: increased rigidity whole cover and new thermal insulation material. It is a composite refractory material, more light, plastic and more resistant for thermal shocks. In the final results, the new tundish cover confirmed in practice prolongation of the cover exploitation from 15-25 000 tones to above 90 000 tones poured steel.

Keywords: tundish cover, thermal isolation, prolongated exploitation

Praca przedstawia rozwiązanie konstrukcyjne pokrywy kadzi posredniej do urzadzenia ciągłego odlewania stali. Istotę doboru optymalnej konstrukcji oparto na uwzględnieniu istniejących naprężeń cieplnych podczas pracy pokrywy i odkształceń, wywołanych tymi naprężeniami. Zamiast stosowanych dotychczas pokryw wykonanych z żaroodpornego betonu oraz płaskiej konstrukcji, nowe rozwiązanie wprowadza dwa elementy: zwiększenie sztywności całej konstrukcji i wprowadzenie nowego materiału izolacyjnego. Jest on znacznie lżejszy, bardziej odporny na wstrząsy cieplne i plastyczny, co ma duże znaczenie przy wykonaniu pokrywy i jej eksploatacji. W efekcie końcowym zwiększono trwałość pokrywy; mierząc ilością rozlanej stali, nowa pokrywa pracuje przez ponad 90 000 ton przelanej stali, zamiast dotychczas 15-25 000 ton.

1. Introduction

Experiences in designing and constructing gained during a years-long production and exploitation of steel fittings (ingot moulds, ladles, mould bottom plates) can and should be utilised in modern steel production technologies [1]. Just there the highest number of cases of extreme thermal loads, where always problems of thermal stresses and deformations, cracks, erosive washing out, etc. occurred, are collected.

2. Experimental

The contemporary way of obtaining semi-finished steel products – by continuous casting of steel – decisively displaced old technologies of obtaining steel ingots. Huge energy savings were achieved due to resigning from ingot moulds, heat furnaces and slab rolling mills. Qualitative benefits of ready products also occurred. However, several problems related to thermal stresses – continuously accompanying steel production – remained unsolved. As an example can serve the tundish cover used in the continuous casting technology. The task carried by the cover is illustrated in the photographs of: the covered tundish – Fig. 1 and the tundish with exploited cover – Fig. 5 and 8b.

Fig. 1. General view of the tundish, which support the cover

The inner surface of the cover is heated during the ladle heating by three gas burners as well as during steel flowing from the tundish to crystallisers. An intensive water-cooling when the tundish is being prepared for the next cycle additionally complicates the presented thermal load conditions. External edges of the cover are placed on the ceramic lining of

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the tundish and heated only slightly. There are 7 technological holes in the longer axis of the cover, and they are subjected to overheating and mechanical failures. These are: 2 extreme holes for stoppers, 3 holes for gas burners and 2 openings for drawing off exhaust gases. The central, largest hole – apart from the task of being heated by a burner - constitutes the source of a continuous supply of liquid steel and loose slag. Due to the necessity of a constant inspection and ladle technological servicing, the temperature of the external surface of the cover should be as low as possible. This condition can be met only when the cover closely adheres to the tundish edge. The efficiency of the tundish heating and working conditions of machine operators will be, in such case, sufficient.

Selection of the optimal cover structure for such complex and variable loads is not an easy task [6], which is proved by a low durability and not sufficient tightness of the cover. The cover shape resembles an elongated plate (with openings) of the ratio of sides being 1:4. Due to structural and technological reasons this cannot be a one-piece plate. Thus, some variants of dividing the plate into 3 or 2 parts were designed. The best one occurred to be the two-piece structure, which will be shown below. Thermal stresses are caused by temperature changes and occur in three cases, which can occur either separately or simultaneously:

1. when a free thermal expansion is limited,
2. at uneven heating or cooling even of a freely supported element,
3. if structural changes accompany temperature changes.

However, thermal stresses do not occur in only one special case: when there are isothermal planes, parallel to external surfaces, it means when the heat flow is stable. Elongations and shortenings caused by such temperature fields are proportional to the distance from the middle surface. The plate curvature is then determined by the following equation:

$$\frac{1}{\rho} = \frac{\alpha\Delta}{h} \tag{1}$$

where ρ – radius of curvature, α – coefficient of linear elongation, ΔT – temperature difference between surfaces, h – plate thickness.

Such case is illustrated in Fig. 2, from which it is seen that stresses do not originate in the curved beam (plate) heated from one side, at a linear temperature distribution (free spherical bending occurs). Stresses can occur only after applying the proper moment e.g. from forces causing hampering of elongations.

Another example of an effective decreasing of the thermal stress level is an application of two-piece plate for open bottom moulds, consisting of a centrally placed mould plug and a supporting it frame on which the ingot mould lies (Fig. 3). In between these parts, at the whole perimeter, there is an expansion gap, which reduces stresses caused by the thermal expansion of the most heated mould plug. In addition, a tendency for erossive washing out of this part by the falling steel stream is lowered. To this effect, the wear index of two-piece plates decreased – in relation to the wear index of monolithic plates – more than two times. The frame was worn in the middle edge only, which suffered radial cracks, while the mould plug was undergoing a gradual, uniform washing out. At the final exploitation period the mould plug was knocked out, and cast iron was poured into the remaining cavity, thus, restoring a total suitability for a further exploitation [2, 3].

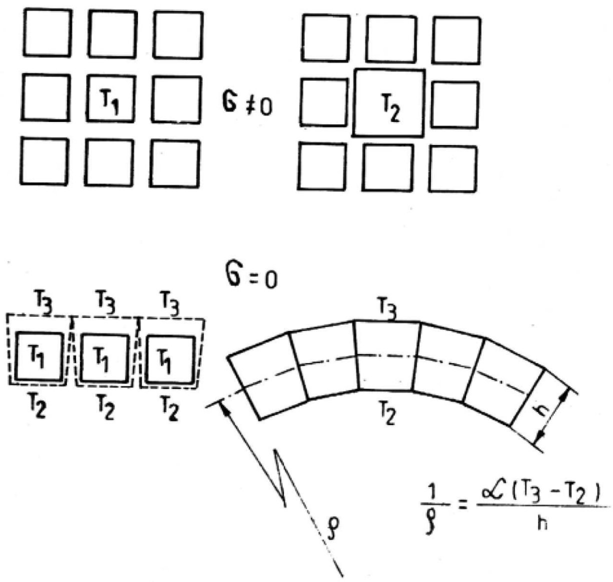


Fig. 2. Example explaining stressless beam (plate) curving at the temperature difference $T_3 > T_2$

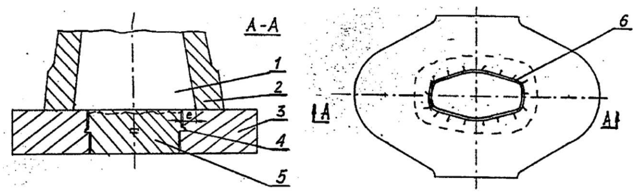


Fig. 3. Two-piece plate for open bottom mould for steel casting (from the top). 1- ingot, 2- ingot mould, 3- frame of the plate, 4- lock, 5- mould plug, 6- expansion gap, e - contact surface of ingot with frame, [2,3]

Installations for continuous casting of steel are characterised by efficient technical solutions, e.g. construction of crystallisers, mechanization and automation of transport and liquid steel pouring etc. However, within the continuous casting of steel technological line, there are still certain imperfections. As an example the tundish covered with the cover, which significantly protrudes from the tundish edge, is shown in Fig. 4. The created gap causes a lot of problems, especially at heating the empty tundish when exhaust gases escape through gaps. Flames escaping during tundish operations lead to heat losses, to worsening working conditions of operators and to risks of accidents.

Just the problem of the proper construction of tundish covers is the main topic of further considerations.

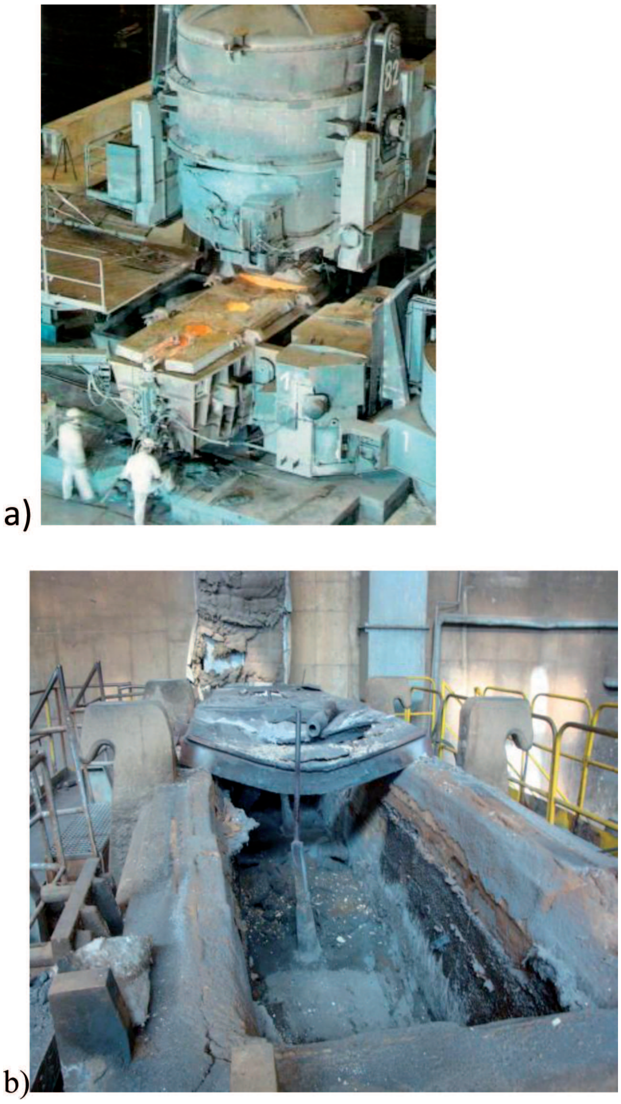


Fig. 4. Examples of thermal deformations of the tundish cover [4]

Fig. 5. 3- part covers after exploitation

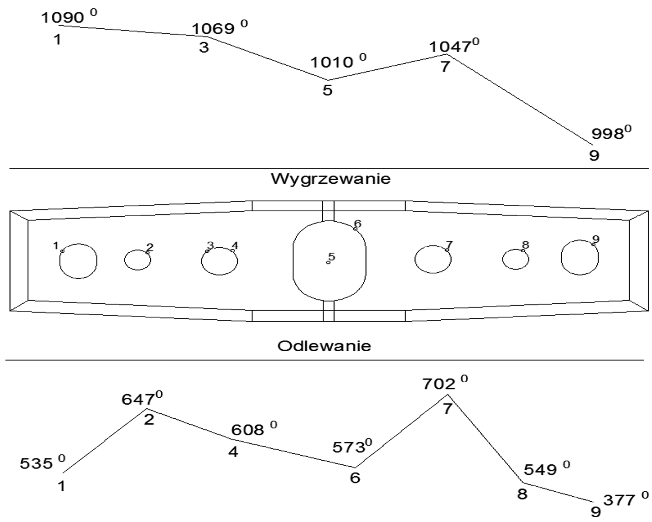


Fig. 6. Temperature distribution at edges of cover holes during the tundish heating and exploitation period (author's own measurements under industrial conditions)

3. Criticism of the existing situation

In the currently used covers the three-part division is applied. The middle element has one large hole, while parts on the side have three holes each. Functions fulfilled by them and thermal loads of their edges are different. The highest temperature is in the vicinity of crossing two axes of symmetry of the tundish, thus the middle cover transfers the highest thermal loads. States of 3-part covers after exploitation is presented in Fig. 5 and 7b.

Author's own measurements, performed under industrial conditions, indicate diversified temperature distribution, at two different states of the cover thermal load, Fig. 6. The upper graph concerns measurements taken at the end of the tundish heating, while the lower one relates to the normal exploitation of the tundish filled with liquid steel (40 tones). A lack of a uniform heating degree in symmetrically placed holes and relatively high temperatures in both cases – is noticeable. Measurements were done by means of a contact thermocouple, however under difficult conditions and not at the same time, and therefore they can be considered only as approximate data.

The temperature difference causes that the heat exchange in the tundish, at a steel temperature of 1540°C, is not equal. It is assessed, that the heat losses on walls and bottom of the ladle is – 2600 W/m^2, when steel flows into the ladle with a rate of 1.26 m/s [5].

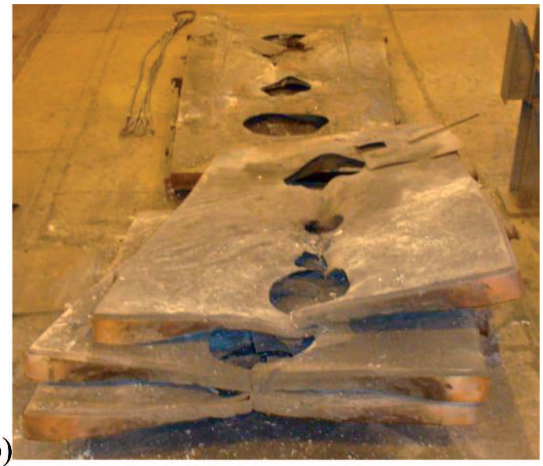
However, there is a lack of even approximate data concerning thermal losses through the cover. Taking into account its construction and materials used for its production, as the cover degradation and loss of tightness is progressing, the process of steel flowing becomes unstable. If all factors influencing the technical state of the tundish with the cover are considered, we will – for sure – notice certain differences in the state of the tundish which is placed, every couple of hours, at the stand above the crystalliser. These are mainly:

– tundish heating temperature,
– state of lining (variable volume),
– tightness of the system: tundish-cover, etc.

a)

b)

Fig. 7. New and worn middle part of the cover with the largest hole

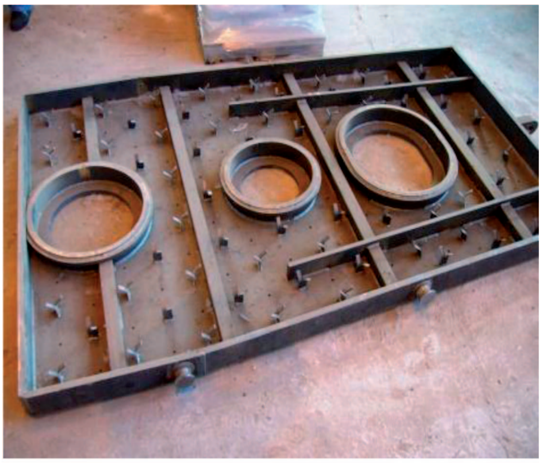


b)

Fig. 8. Side cover made of 25 mm sheet, strengthened by transverse and longitudinal shaped elements, shown without its refractory lining, and worn covers

Thus, from these reasons the middle part of the cover is worn as the first one. Cover edges crossing the longer tundish axis are heated to a such degree that due to oveplasticity of the material they bend under own weight and stresses, loosing their stability. Of course, the effect of bending, due to one-sided heating, aggrevates this problem.

Side covers (Fig. 8a) are welded of thick-walled sheets. They should be considered as steel boxes, which are bending under an influence of one-sided heating and the cover losses its tightness. Therefore certain strengthenings are applied. However, this is specially unfavourable during a tundish heating process.



a)

Round holes of the cover fragment (Fig. 8a), from the left, are intended for: drawing off exhaust gases, introduction of a burner and installation of a stopper. Catches facilitating mounting the refractory concrete, which is aimed to assure the thermal insulation of steel elements, draw attention. Unfortunately during exploitation the refractory concrete cracks relatively fast and gaps allow heating of a steel mantle, which in turn leads to the cover deformation (Fig. 4). This fact is the first and the most important reason disqualifying the applied thermal insulation and causing unsatisfactory exploitation life of the cover.

The second unfavourable factor of the structure is its large weight and resulting from it the high thermal capacity. The very shape of the cover, welded from flat sheets, leaves a lot to be desired. It is well known that flat roofs have lower bending strength than convex roofs. The mentioned above factors decided that completely new concept of the cover was selected. The relatively light roof supported on a channel bar surrounding the ladle edge was applied and this roof was filled with elastic and fibrous insulating material.

The cover shape depends on the ladle shape, and construction difficulties increase significantly when it changes from a circular to rectangular shape. The higher ratio of the longer side to the shorter one, the larger differences in shapes of the temperature, stress and deformation fields. The tundish destined for two lines of the continuous casting machine has especially unfavourable rectangular shape, in which the ratio of sides is app. 4. In such case a complex heat transfer should be expected, depending, among others, on a metal flow through the ladle, in which the so-called 'dead' zones of a weak flow intensity, are formed. Liquid steel after out flowing from the main ladle nozzle is immediately moving to the escape holes zone above the crystalliser. To this end, the effective time of liquid steel being within the influence zone of the ladle slag is very short. Various partitions and ceramic lining shapes can prevent this situation and improve conditions of hydrodynamic flow. The point is, that the creation of better conditions for the refining slag influence is needed.

All technological operations in preparation and exploitation of the tundish are accompanied by a high temperature, thermal radiation and toxic gases evolution. Metal platforms, stairs and balustrades are often heated above the allowable values that are why efforts to obtain good airtight sealing of the process are reasonable. Therefore ensuring a good tightness of the tundish edge and cover to prevent the exhaust gases evolution is important.

Summing up: there are at least three reasons of large deformations of the cover made as flat steel box with refractory concrete lining, the so-called 'old covers'.

1. Flat covers during their heating change into concave covers. Their roundness is directed towards the heat source, which influences concrete cracking and further temperature increase in the steel plate. In the period when the concrete cracks the difference between thermal expansions of metals and ceramic linings occurs. Thermal deformations cause faster heating and increase degradation, which is growing with each cycle. Thus, we are dealing with thermal deformations of each heating cycle, it means with instantaneous deformations vanishing when temperatures become equal and with durable deformations growing after each cycle. In the innovatory structure the roofed cover substituted the flat cover with a convexity pointing up. In such system the temperature difference will not cause so large concavity as in case of a flat cover.
2. Large plates thickness (mainly: 25 mm), of which flat covers were made, does not protect the required stiffness, regardless of applying special strengthening (Fig. 8a). Innovative covers are made of thinner plates and lighter materials, and in effect their total weight was lowered three times.
3. Hard and brittle refractory concrete applied for insulating of covers has been a great disappointment due to disappearance of its insulating ability already after a few cycles. In the innovatory solution the new high-temperature ceramic, fibrous material, which retains its elasticity and insulation properties during the installation and exploitation periods, was applied.

4. Concept of the innovative cover

Due to structural reasons the tundish cover, having 5 large holes, must be divided into 3 or 2 parts. The 3-piece division, despite symmetric thermal loads, constitutes the weakest part of the whole structure, since the largest hole, which edges are heated to the highest temperature exceeding 1000°C, is in the middle part. This part of the cover is supported from two sides only, and its narrow sides are also extremely heated. The effects are seen in Fig. 4b, 5 and 7b. Attempts of obtaining the required stiffness by increasing its size, containing neighbouring holes, were not successful since durability of such plate with 3 holes was still unsatisfactory as compared with two side parts of two holes each. On the grounds of the performed analysis it was possible to state, that reasons of the fast exploitation wear were not only the structural flatness and not suitable insulating material but also dividing boundaries in between which gases heating the steel structure were penetrating (see Fig. 5). A high ability of heat storage of massive flat sheets caused maintaining too high temperatures on the cover surface by the whole period of its being on the tundish. Radiation from such large surface renders difficult the work of operators.

In the innovative cover the concept of 2-piece division in connection with a light steel structure and excellent thermal insulation was applied. Such structure, built on the channel bar surrounding the whole tundish perimeter, is presented in Fig. 9 and 10. The roof was obtained due to sheets welded on at angle to the channel bar. In such way the fraction of the flat roof was limited to minimum, especially since its significant part was taken up by the holes.

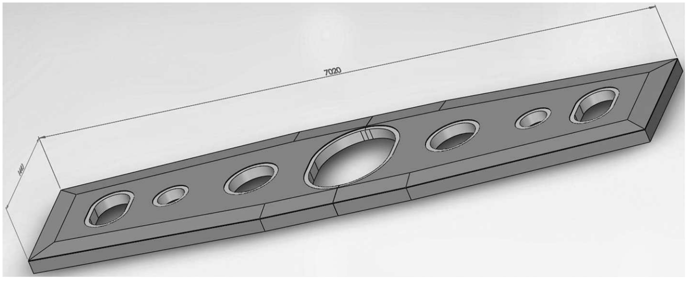


Fig. 9. Roofed cover with 2-piece division

As can be seen, the cover in the innovatory version consists of two identical parts and only one side-joining surface. The roof shape as well as its excellent insulation from the bottom, causes that it became less sensitive to thermal loads during all cycles of heating, exploitation and cooling. Already its outside view inspires confidence, in accordance with the saying: 'nice looking things – must be good things', (see Fig. 10).

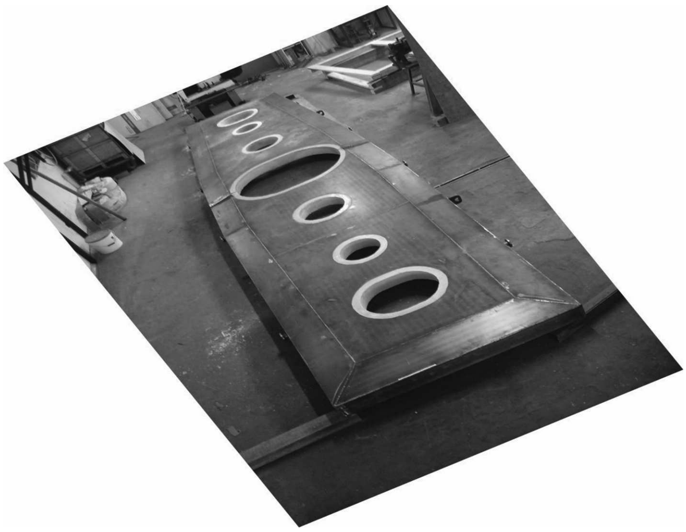


Fig. 10. 2-piece innovatory cover, view from above

The holes in the structure shown in Fig. 10 were made of a composite refractory material. It was characterised by a good fire-resistance but a weak mechanical strength. Technological operations, such as installation and servicing of stopper devices, introduction of the main steel stream or slag-charging are always accompanied by splashings, formation of slag buildup at the hole edges, etc. During the cleaning procedure brittle materials are often damaged, which can be the source of losses and due to that – an excessive cover heating. Conditions under which the cover 'works' during heating and filling with liquid steel are well illustrated in photographs (Fig. 11).

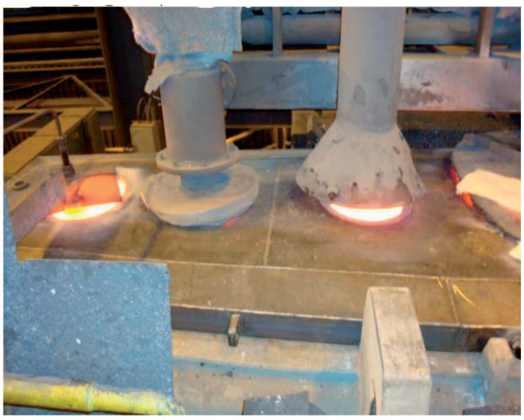


Fig. 11. Cover during heating and filling with liquid steel. White edges of insulated holes indicate that a temperature exceeded 900°C

a)

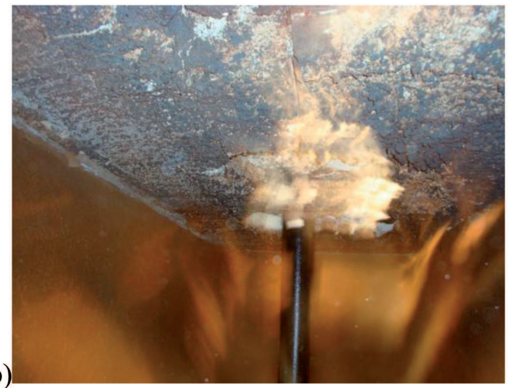

b)


Fig. 12. Insulating material of the cover after a certain exploitation period – a) Magnified fragment of the cover after a much longer exploitation – b)

The new cover is lined with a pressed fibrous material [7], which due to its elasticity, without using glue, mounted by means of catches, stays in place during the whole exploitation period. This material does not require any covering, and steel or slag splashings are peeling off under their own weight. The view of the refractory lining after a certain number of thermal cycles is presented in Fig. 12.

The example of extremely difficult conditions under which remains the cover after each cycle is presented in Fig. 12b and 13. In order to clean the tundish – from steel and slag residues – water, which immediately changes into overheated steam, is introduced. This steam separates residues of shrinking steel from the refractory lining. The procedure influences also the cover lining however, does not cause to it any harm. After taking off the cover the so-called 'bears' are drawn out, remaining contaminations are removed, the cover is replaced and handed over for the next heating cycle.

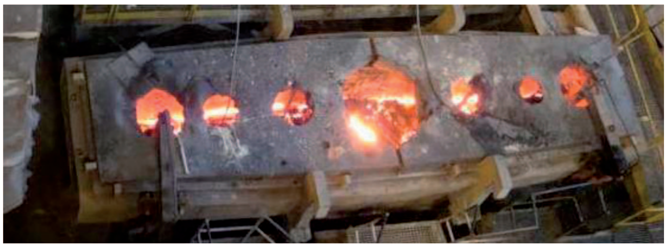


Fig. 13. Ladle with the innovatory cover after finished cycle of pourings

5. Final remarks

The presented prototype of the innovatory project of the tundish cover fully confirmed the rightness of structure and material assumptions. It specially concerns the division into two pieces, application of the light, roofed steel structure and high-quality refractory lining. Obvious benefits in energy consumption were obtained (shorter heating time due to a tightness improvement), prolongation of exploitation periods, improvement of occupational safety and heath conditions and better work organisation during operations of tundishes. In a similar fashion as the separation of a 'hot' part and dividing (in cases of plate for open bottom moulds), the application of a high-quality insulation and the proper shape of the cover, led - in effect - to structures not being highly sensitive to thermal stresses, which assured the high-durability of such structures. Results of using seven covers, confirmed in practice, allow to determine the following effects resulting from the new structure application:

– prolongation of the cover exploitation period from 15-20 000 tones to above 70 000 tones of poured steel,
– decreasing heat emission in the tundish heating process as well as on the casting stand,
– improvement of conditions of occupational safety and health on both workstands,
– possibility of repairs and renovations of partially worn covers.

Further and detailed assessment of effects will be possible after a longer exploitation period of a larger number of covers.

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