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Application of Liquid Glass Mixtures with Improved Knocking-Out Ability in Castings Production for Railway Transport

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Abstract

Analysis of the use of the Russian materials (liquid glass and softening additives) has been made in accordance with the modern requirements for use in the technological processes of casting as binding materials in the production of large-sized steel railway casting. The reasons for poor knockout of liquid glass mixtures have been investigated. A complex action softening additive has been recommended for a better knocking-out ability. This solution provides a softening effect at the points of maximum formation of the liquid glass matrix strength in the processes of polymorphic transformation of the material under the influence of elevated temperatures as the result of filling the mold cavity by the melt. It has been shown that the use of additives of complex action leads to the decrease in the specific work of the knockout by four – seven times depending on the composition of the mixture and the design features of the casting. Experimental-industrial tests of the proposed method for softening the liquid glass mixtures have been made and the "Front Buffer Stop" casting has been made (for the rolling stock of locomotives and railway wagons). The tests confirmed the effectiveness and expediency of implementation of new liquid glass mixtures with softening additives in conditions of foundry enterprises.

Keywords: Molds and cores, Liquid glass mixtures, Knocking-out ability, Softening additives, Steel casting

1. Introduction

Distinctive features of casting in transport railroad engineering are the massiveness of castings in combination with large overall dimensions. The production tasks are complicated by the complexity of the castings' designs determined by the presence of various dimensional transitions and articulations of the mating walls' thicknesses under the strict requirement to observe cast quality [1]. The resulting parts must have strength, durability and operating reliability in given climatic conditions [2]. The above mentioned issues determine the complexity of the technological process production implementation.

The current level of the production development regularizes not only the provision of technical and technological standards to ensure the quality of casting but also the environmental safety along with the sanitary and hygienic working conditions of the personnel [3-5].

The production of steel railway castings is based on the use of the wide range of various resin binders [6-8]. Along with ensuring manufacturability and quality, resin binders significantly increase the casting self-cost with simultaneous deterioration of the sanitary and hygienic working conditions at workplaces and lead to a sharp complication of the environmental situation in the areas where such production facilities are located. This manifests itself in increasing the level of occupational diseases among workers accompanied by degradation of the natural environment.

It has been established that the use of phenolic resins leads to the growth of a variety of allergic and oncological diseases [9]. This is typical not only for production personnel but also for the population living in a close proximity to industrial enterprises that use the above mentioned resin binders [10] in their technological cycle. Such results were obtained through a multi-year study of the health status of workers and the population in Sweden [11].

The importance of the ecological imperative has led to the adoption of a special directive regulating the composition of resin binders used in the technological processes of different industries not only in foundries in the EU countries. In particular, it is Directive 2010/75/EU of the European Parliament and of the Council of November 24, 2010: "On Industrial Emissions: Integrated Pollution Prevention and Control". In Russia, the use of such resins is not limited to the legislative level that poses risks to serious health threats for both the personnel of enterprises and the population living in a close proximity. In addition, modern resin binders used in Russian enterprises that meet the increased requirements for manufacturability of the casting process are made from imported raw materials, which in turn determines their high cost [9, 10].

To date, binder materials based on liquid glass are among the most environmentally friendly and cost-effective. At the same time, the expansion of the use of liquid glass mixtures in the foundry industry requires solving the problem associated with their difficult knockout [12]. The knocking-out ability is a complex technological characteristic inherent in sand casting technologies and determining the labour-intensity of the operations of extraction of a casting from a sand mold or a sand core from a casting cavity. There are examples of some positive results achieved in the direction of improving the knocking-out ability of liquid glass mixtures through the use of microsilica addition, which allows to reduce the silicate level in the binder [13], as well as through the use of complex softening modifiers based on hydrolytic lignin, bentonite and vermiculite [14].

The purpose of this study is the comprehensive technological assessment of the possibilities of using casting mixtures on liquid glass with the lighter knockout in the production of steel castings for railway transport.

2. Promising technological solutions for the production of castings without the use of resin compositions

There are known scientific developments that make it possible to avoid the use of resin compositions due to the use of inorganic binding materials [2, 4, 5, 15]. This approach in case of its successful implementation eliminates the negative impact on the personnel and significantly improves environmental performance.

In modern Russian conditions, this approach is considered as a tool for an integrated solution for the production of castings of this group that includes: reducing costs, improving working conditions, ensuring environmental safety of the production [16] and the possibility for the heavy use of the domestic materials for the foundry needs. This innovative way not only solves the import substitution tasks but also creates new workspaces due to the need to develop the production of domestic bonding materials: liquid glass and softening additives. This can be achieved by involving the production of castings of domestic bonding materials, which have been undeservedly displaced from the foundry market of binders, in the technological process.

The main reason restraining the widespread use of the liquid glass as a binder for the production of the steel railway castings is the unsatisfactory knockout of sand cores and molds based on them. Dynamics of changes in the strength characteristics of liquid glass compositions is characterized by the presence of two strength peaks during the heating of the mixture when casting the mold with metal melt (at temperatures of 300 and 800°C as shown in Fig. 1).

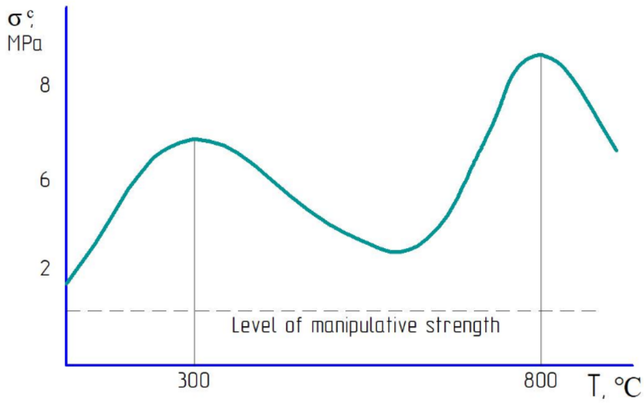

Fig. 1. Characteristic curve of the change in compressive strength of liquid glass mixtures during heating

Considering the scale of the bonding materials use in the foundry [17] and the specificity of the polymorphism of the liquid glass materials in the heating process, it has been suggested to use a combination of materials including a block of components working on softening at low temperature range (200-300°C) and a block of components operating at high temperature range (700-800°C) as a softening modifier.

The proposed technological solution is based on the combination of the modifier components degradation processes with the processes forming the maximum strength of the liquid glass during its polymorphic transformation when the mixture is heated (Fig. 2).

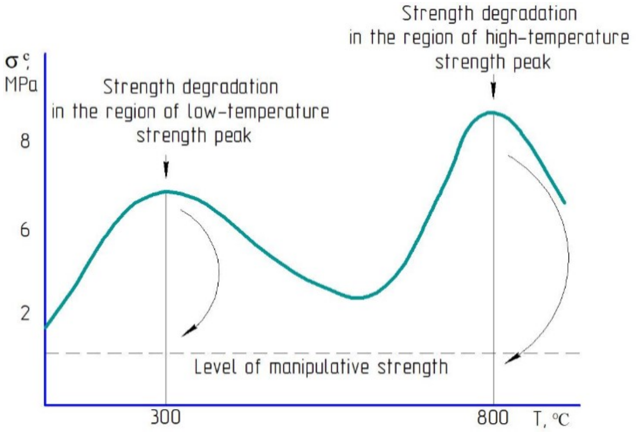

Fig. 2. Concept of strength degradation of liquid glass mixtures

It has been proposed to take the technical lignin presented in the alkaline format, in particular, hydrolytic lignin (pH ~10-12) as a raw material for softening the liquid glass composition in the low-temperature region (peak in the 280-300°C region, as shown in Fig. 3), that is a bulk waste of the hydrolytic production.

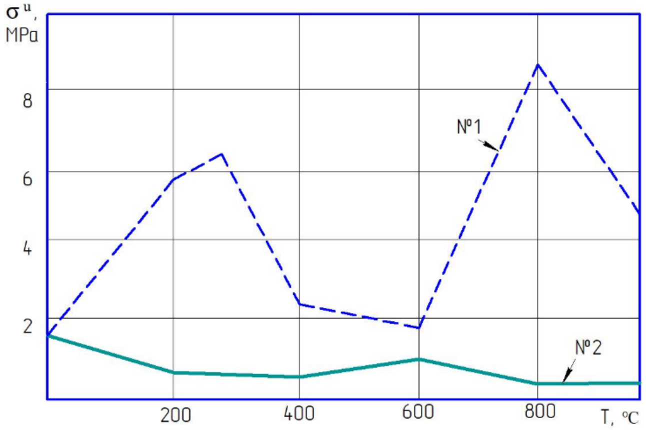

Fig. 3. Residual strength of liquid glass mixtures of various compositions: No. 1 – model composition of the mixture on liquid glass without softening agents; No. 2 – mixture composition with softening additive [16].

This product is manufactured in Russia; it is an inexpensive and not scarce material. The alkaline base of hydrolytic lignin ensures mutual combination with the liquid glass. For weakening in the high temperature region (peak in the region of 800°C according to Fig. 2), it has been suggested to take inorganic materials – clay and/or vermiculite.

The behavior of clay in the structure formation processes has been studied in the investigation [18] where the softening role of metakaolin in the process of the composition strength formation has been shown in [19].

3. Investigation of the effectiveness of the proposed method of the liquid glass binder softening practical application by means of an example of the core sand mixture (materials and test methods)

Pilot-scale tests of the proposed compositions of core sand mixtures have been carried out in the production conditions (Table 1).

Table 1.
Compositions of core mixtures for pilot testing

Components	Proposed mixture, wt.%	Plant mixture, wt.%
Sand 1K02B	100	100
Liquid glass M2.6	5.0	5.0
Sodium carbonate	1.0	1.4
Asbestos tailings	2.0	2.5
Softening additive (technical lignin + kaolinitic clay, 1 : 1)	1.6	-

The following materials have been used as raw materials: high-silica sand of 1K02B grade as a filler, liquid glass with silicate module of 2.6, technological additives (asbestos tailings, sodium carbonate) and also the proposed softening additive including technical lignin and kaolinitic clay.

To prepare the test mixes, a filler (quartz sand), technological additives and a softening additive were initially dry mixed for 5 min, then liquid glass was added and mixed together for 15 min. The energy costs index when knocking out the core has been determined by the techniques [2, 20]. The mixture properties have been determined by the standard techniques: compression strength in uncured "raw" state of the mix, bursting strength in cured "dry" state of the mix (according to GOST (Russian standard) 23409.7-78), humidity (according to GOST (Russian standard) 23409.5-78), gas permeability (according to GOST (Russian standard) 23409.6-78). Physical and mechanical characteristics of the investigated mixtures are shown in Table 2.

Additionally evaluation of the investigated core sand mixture knockout has been made according to the technological sample for wall thicknesses of 5 and 20 mm. Technological samples were filled with ASTM A352 Grade LCC Steel at a temperature of 1580°C.

Cores from the prepared liquid glass mixtures (Table 1) in the form of cylindrical samples 50×50 mm were made (by the procedure according to GOST (Russian standard) 23409.7-78) that were dried in a drying oven (for 45 minutes, at 220°C). After being removed from the drying oven, they were cooled to room temperature. The cooled samples were placed in a mold and filled with steel at a temperature of 1580 °C. Upon extraction from the mold the castings were cooled in the air and then the core print was separated. After this, the casting with the core was weighed to determine the total mass; subsequently the core was removed on a standard laboratory rammer (model 5033A). Upon completion the process, the casting was weighed and the calculation of the core mass and the work performed was carried out. Results of the knockout specific work measurements are given in Table 3.

Table 2.
Physical-mechanical properties of the mixtures

Properties	Proposed mixture, wt.%	Plant mixture, wt.%
"Raw" compressive strength, kg/cm^2	0.27	0.23
Moisture, %	3.6	3.7
Gas permeability, a.u.	311	203
Tensile strength of dried samples	3.1	2.7
Knocking-out ability (visually, after removing the casting from the mold)	Spent mixture of the core poured out with a slight tapping on the casting body, the knockout did not present any difficulties	The spent foundry core was a solid, caked monolithic body, the knockout is difficult

Table 3.
Knockout specific work characteristics

Wall thickness of technological sample	Knockout specific work for proposed mixture, J/g	Knockout specific work for plant mixture, J/g
5 mm	0.16	0.67
20 mm	0.08	0.60

Results in Table 3 show that the work of the knockout using the softening additive with the technological sample wall thickness of 5 mm decreases by 4.1 times and with the wall thickness of 20 mm it decreases by 7.5 times. This characterizes the effectiveness and expediency of using the softening additive.

The proposed additive has been recommended for use in the technological process in the production of the casting "Front Buffer Stop" with a weight of 104.5 kg. The produced core along with the plate was installed on a cart and sent to the dryer. The curing of the core was carried out by thermal drying in the single ended drying unit under the drying parameters accepted for the factory composition of the mixture (Table 1): the drying time was 90 minutes at a temperature of 240-250°C, followed by a 60 minute cooling in a cooling furnace.

4. Discussion

Figure 4 shows the railway casting "Front Buffer Stop" from ASTM A352 Grade LCC Steel.

Fig. 4. Appearance of the casting "Front Buffer Stop" obtained using a liquid glass mixture with softening additive

The molding core treated mix poured out under a slight tapping on the casting body and the knockout did not present any difficulties. The resulting casting had a clean surface without any burning and surface defects.

An illustrative point is the nature of the foundry core softening at the time of casting extraction from the mold. The surfaces of the core, which is in direct contact with the casting (molten metal), partially destroyed and crumbled. These surfaces were represented as black crumbs with a size of 2-4 mm and sharp edges and have a clearly defined cohesive nature of destruction. With increasing the distance from the point of contact of the core body with the casting and deepening into its center, the particle size increased. With shaking, the spent core crumbled almost completely, except for the central part, which was a round and irregularly shaped lump. The remaining sintered part of the core was destroyed by light tapping with the hammer.

Such a state can be explained by the fact that a complex softening additive has fully worked out in the surfaces of the core that have come into contact with the steel melt. At the moment of the start of the glass transition process (warming up in the region of 300 °C), the process of thermal decomposition of the lignin simultaneously started, accompanied by abundant gas evolution. The bubbles of the formed gas was dispersed in the body of the emerging glassy mass, disrupting its continuity and acting as a stress concentrator; evidence of this is the cohesive nature of the destruction observed in consequence. In places with a higher core heating temperature, the intensity of gassing of the lignin was greater; for this reason, the surface layers of the core that came into contact with the melt collapsed most strongly, as confirmed by smaller particles of the spent core mixture.

As the core warms up, the lignin component burns out completely (at the points of contact with the metal). At the same time, due to the polymorphism of liquid glass, in the temperature range corresponding to 800 °C, there is a second, stronger in influence, peak in the strength of the glassing part of the core (see Fig. 3.). However, with an increase in the heating temperature, the second component of the softening complex, clay, entered into operation. The mechanism of its action was that, in the area of elevated temperatures (for clay ~800 °C), constitutional moisture contained in the mineral in the bound state under normal conditions is released. Standing out in the form of vapor, it plays the role of a softener, by analogy with the lignin component, but at a different, higher, temperature level.

In the case of using the components separately, if it is lignin, then the effect of softening is leveled by "recrystallization" of the liquid glass composition in the high-temperature region. In the case of using only clay, in quantities that do not impair the technological properties of the mixture at the molding stage, the effect is not stable, apparently due to the lack of a reinforcing agent – water vapor. In addition, in some cases, the use of clay only was accompanied by the formation of chemical burns on the surface of the casting. This possibly can be explained by the fact that the water released from the mineral tends to be replaced by metal. In the case of combined use (clay and lignin), the resulting free "juvenile" bonds appear to be slagged with ash from the burnt lignin deposited on the surface of the kaolin.

A more detailed study of waste core mixture revealed the presence of gas bubbles in its particles. The size of the bubbles in the structure of the mixture increases with distance from the points of contact of the metal with the core elements, which is explained by the different intensity of gas evolution by the components of the softening additive. After complete cleaning, the casting was cut; gas shells or sieve porosity was not detected.

When analyzing the obtained results it is expedient to determine the main tasks for the further development of the technology of applying softening additives in the production of castings:

1) specification of the softening agent components optimal proportion alongside with studying the mechanisms of their action in specific concentration limits to provide an effective process of the control over the softening effect;
2) the mixture composition optimization aimed at reducing the liquid glass mass fraction in its composition, by modifying it [21] and controlling the processes of the structure formation in the "filler-binder" system [22, 23] depending on the casting nomenclature by weight, complexity design, accuracy requirements;
3) development of the liquid glass modifiers providing a reduced mass fraction of the liquid glass in the mixture [24, 25];
4) transition to cold hardening mixtures with the liquid glass suitable for using this softening additive;
5) development of the foundry molding sand compositions with the use of regenerated sand, optimization of the composition of mixtures;
6) development of a universal mixture composition for the technology with the purpose of its application in the manufacture of molds and cores; research of the conditions of this mixture application depending on the weight of the casting, the complexity of its design, overall dimensions, quality requirements;
7) investigation of the quantitative values of the gas evolution as a result of the thermal destruction of the mixture in the process of its application and assessment of changes in the sanitary and hygienic working conditions and environmental safety;
8) investigation of the softening mechanisms in the low-temperature region (300°C) with the aim of the potential application of the liquid glass mixtures for the production of aluminum castings.

The results show an idea of the softening effect of the complex additive in the core mixture on a liquid glass basis, show the fundamental possibility of using liquid glass foundry binders that meet the current level of requirements, and suggest a possible replacement of environmentally hazardous and expensive resin binders. However, this is a particular example of the implementation of a technical proposal that improves the production technology of small and medium-sized steel castings for railway transport at a specific enterprise. In order for such improvements from the "here and now" state to be transformed into a full-fledged and universal technology "in general", from a particular example to a general rule, into a technology allowing to produce certain classes of castings on a mass scale, it is advisable to explore various combinations and compositions of the entire spectrum the materials used in this process.

First, about the components. Liquid glass as a material is a complex chemical substance that can vary in composition of components and properties, which depend on the features of the technological processes of its production [26, 27]. In the present work, the material was used that is present on the Russian market: GOST (Russian standard) 13078-81 "Sodium liquid glass". It would be advisable to test various versions of the compositions of this material to determine the best composition. Technical (hydrolytic) lignin, as a component of the softening composition, is a waste product, and therefore has potentially unstable properties, due to the variation of its chemical composition [28]. However, this may affect, to a certain extent, the processability of the mixture, since the temperature of thermal decomposition will not change significantly.

Secondly, about the quality of castings. It is advisable to try out various versions of the compositions of liquid glass mixtures, not only for their knocking-out ability, but also for other important indicators, for example, flexibility. This criterion is important for large-sized thin-walled steel castings [29].

Third, the equipment. The characteristic specific feature of the present stage of the foundry industry development is that there is a complex of specialized equipment under a certain binder material. For this reason, to advance the technology it is advisable to establish cooperation with various manufacturers of mixing preparation equipment.

5. Conclusion

The principal possibility of using the developed softening additives on the basis of technical lignin and kaolin clay for liquid glass mixtures is established. The effectiveness of the proposed additive, performing softening function at the stages of strength peaks during polymorphic transformations of liquid glass, is proved in accordance with its physical nature. It has been experimentally determined that the work of punching using the proposed additives will be reduced by 4-7 times, which makes the liquid glass mixture comparable in the knockout index with resin binders. The practical possibility of using the proposed softening additive for liquid glass mixtures in the production of steel castings for railway engineering is shown. The main tasks of developing the technology of applying softening additives in the production of large castings are determined.

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