Vrnjačka Banja, Serbia

14th INTERNATIONAL CONFERENCE ″RESEARCH AND DEVELOPMENT IN MECHANICAL INDUSTRY″

RaDMI 2014

PROCEEDINGS

Vol. 1

Editor:

Predrag V. Dašić

Topola, Serbia
18-21 September 2014.

Publisher: SaTCIP (Scientific and Technical Center for Intellectual Property) Ltd.,
36210 Vrnjačka Banja, Serbia

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Approved by:
Decision no. 006/2014 from 01-06-2014 from SaTCIP Ltd., Vrnjačka Banja (Serbia)

Circulation: 50 exemplars

Printed by: SaTCIP (Scientific and Technical Center for Intellectual Property) Ltd.
36210 Vrnjačka Banja, Serbia

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SESSION A
RESEARCH AND DEVELOPMENT OF MANUFACTURING SYSTEMS, TOOLS AND TECHNOLOGIES, NEW MATERIALS AND PRODUCTION DESIGN

14th International Conference
″Research and Development in Mechanical Industry″
RaDMI-2014
18-21 September 2014, Topola, Serbia

ADVANCED TECHNOLOGIES FOR PRODUCTION OF IRON CASTINGS WITH PREDETERMINED STRUCTURE AND PROPERTIES

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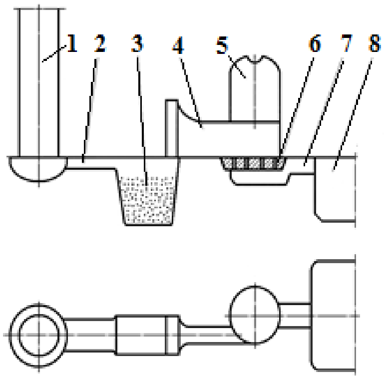
Summary: *On the basis of the field experiments in the production of advanced and industrial castings prospective resource-saving technological areas of the method of in-mold inoculation of molten iron for castings with a given structure and propertiesis investigated in the work. The proposed areas can be recommended for implementation at enterprises of foundry industry for the manufacture of a wide range of high quality products.*

Keywords: *iron castings, gray iron, white iron, ductile iron, bilateral manufacturing technology, different structure and properties, inoculant, additive, in-mold inoculation, reaction chamber.*

One of the most common structural materials for a wide range of molded articles is iron by far. The share of iron castings in the world production of cast products today is more than 70% [1, 2].
Widespread use of this constructional material in comparison with other alloys is due to the most favorable combination of its foundry, technological, mechanical and performance properties. Furthermore, iron is a readily available and relatively cheap material, melted in relatively simple melting aggregates of different types, possessing good workability, and its use for the manufacture of castings allows to reduce the machining and to increase the process yield of castings [3, 4].
However, to maintain its leading position among the cast alloys in the future, taking into account the ever-increasing demand, which pushes the industry for quality and properties of metal parts and pieces, there is a requirement for the development of new, more effective technologies, or further development of existing technologies for the production of iron castings with improved structure and improved physical, mechanical and operational characteristics.
It is known that one of the ways to improve the structure and to enhance the mechanical and performance properties of iron castings is the melt modifying treatment [3-5].
Currently, the foundry practice uses many ways of modifying the liquid cast iron: on the furnace spout on the melt release into ladle, in sealed and open ladles, in an autoclave, in a stream of cast metal, in gating bowls and other elements of gating systems, etc. [4 -7].
Of the developed modifying methods lately in the industry gain ground the so-called methods of the late modification of cast iron, of which one of the most effective, technologically, economically and environmentally beneficial is processing of the melt directly in the mold, known as "Inmold-Process" [8-13].
Modification of iron by this method is carried out directly in the mold by placing granular inoculant in a special container or in a special mold cavity – an intermediate flow reaction chamber of the gating system, located in the path of the melt to the casting (Figure 1).



1 – riser; 2 – inlet into the reaction chamber; 3 – reaction chamber with modifier; 4 – exhaust port of the reaction chamber; 5 – slag trap; 6 – strainer; 7 – feeder; 8 – casting.

Figure 1: Diagram of inmold inoculation of cast iron (Inmold–Process)

During casting the modifier in the reaction chamber interacts with the flow of molten metal and moves into the volume of the mold cavity where it is finally assimilated with metal casting [8-13].

Compared with other methods of modifying the melt, the Inmold Process ensures desired and more uniform structure and properties in all sections of castings, reduces modifiers' flow, significantly reduces the loss of active elements on oxidation, excludes heavy smoke emission, luminescence and pyroelectric effect, increases productivity and creates conditions for the automation of modifying and filling processes.

In addition, inmold inoculation allows to produce castings in a short time, at a lower cost and does not require installation of several melting units, auxiliary equipment or other units and special devices in the shop when introduced into production [8-13].

In world and domestic practice inmold melt treatment is more commonly used in the manufacture of small and medium-weight castings of ductile cast iron with nodular graphite in a batch and mass production [6, 8-11, 13-15].

At the same time, thanks to the above mentioned and other advantages of the modification technology of cast iron in the mold there opens up the possibility of using it not only for the purpose of nodularity in cast iron, but also in other manufacturing processes of cast iron parts.

This study proposes, develops and investigates new promising technological processes of production of iron castings using the method of treatment of the melt inside the mold, which includes:

- inmold modification of liquid iron prone to crystallization chill (WCI) and of gray cast iron, with the release of crystallizing graphite in the free state (GCI), by graphitizing, carbide-regulating additives or spheroidizing additives when cast into dispensable sand molds;
- dual technology (including the "counter") processing of the he initial melt of white or gray cast in the mold;
- a method for producing castings with different structure and properties in a single mold from one initial melt;
- bilateral manufacturing technology, bilayer and multilayer moldings with differentiated structure and properties of the individual zones (sections) from a single melt base when poured into disposable molds, as well as into a rotating centrifugal casting mold.

Studying the technology of inmold inoculation of the base iron melt prone to crystallization chill (WCI) and gray cast iron, which crystallizes with the release of graphite in the free state (GCI), by graphitizing, nodularisation and carbide-regulating modifiers there was conducted the research on the choice of types of the listed groups of additives (modifiers) determining the optimal quantity and their particle size distribution and parameters of gating-modifying systems, the reaction chamber flow parameters and degree of filling for accommodation and modifying other granular additives.

The results of numerous experimental studies allowed to establish that for graphitizing inmold cast iron, prone to chill crystallization (WCI) ferrosilicon brand FeSi75 should be used in the mold, with a particle size of 5.0 ± 2.5 mm [16, 17] in an amount, introduced into the reaction chamber, from 1.0 to 2.0% by weight of the treated melt.

Concerning the modifiers for spheroidizing treatment of gray cast iron with a tendency towards crystallization and graphite separation in a free state (GCI), the best results were obtained using complex ferro-siliko-magnesium alloys with magnesium content of about 7.0% (FeSiMg7 and VL63 (M)) with the particle size of 5.0 ± 2.5 mm placed in the reaction chamber in the amount of 1.5 ... 2.0% by weight of the casting [17, 18].

Certain problems arose when processing initial gray cast iron prone to crystallization with graphite precipitation in a free state (GCI) by carbide-regulating additives to increase the hardness and wear resistance due to the formation of chilled cast iron.

It is established experimentally that carbide-regulating additives for widespread iron-carbon alloys such as ferrochromium of FeCr200 and FeCr900 grades, when inmold processing almost did not react with the liquid metal stream (irrespective of the particle size, temperature and speed of filling a form by the melt) and after casting a substantial amount remained in the reaction chamber runner systems in the initial state.

It is common knowledge that magnesium is an efficient carbide-regulating element. However, introduction of magnesium into the molten cast iron directly in a mold is followed by vigorous oxidation reaction (combustion), which leads to rather large unsafe splashes of metal from the sprue of the mold.

To reduce the activity of the magnesium it is administered into the melt in the form of complex ligatures or mixed additives. After a series of additional studies it has been found that low-percentage mechanical mixture of magnesium powder with a neutral to graphitization filler, such as ferromanganese, did not provide a through-chill of a cast in massive sections of the sample (50 mm and above). Mold filling with high-percentage mechanical mixture was also accompanied by pyroeffect, magnesium exhaust fumes and unsafe splashes of molten metal from the sprue funnel [17, 19].

It is established experimentally that the most effective additive for inmold carbide-regulating inoculation of cast iron, prone to crystallization with separation of graphite in a free state (GCI) is a nickel-magnesium ligature of NiMg15 and NiMg19 grades and cerium misch metal Tse48La28Mg3 with a particle size of 1.0 ... 10.0 mm, added to the melt in an amount up to 2.0% [17,20].

From an analysis of the literature and practice it is known that the efficiency of liquid iron modifying processing can be increased by using an integrated or so-called "counter" double modification [21-23].

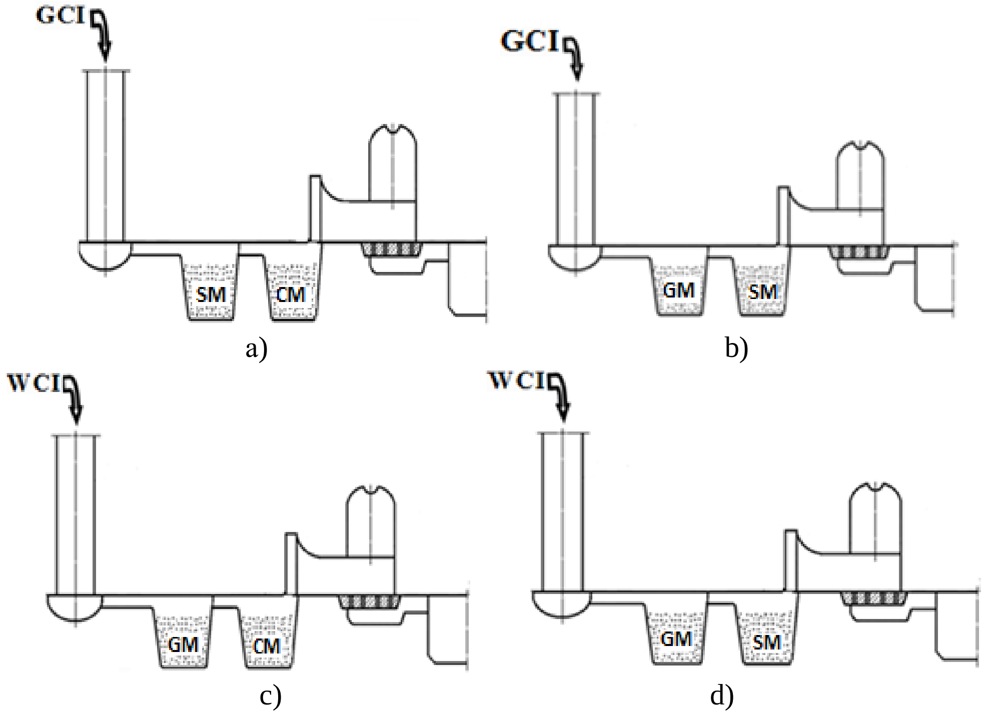
With this in mind, the work proposes and studies dual (counter) technology of inmold inoculation of cast iron, which consists in processing of the initial white or gray liquid iron consistently different in chemical composition and functional purpose of modifying additives placed in two reaction chambers of the gating system, next to each other by the path of the melt in the mold cavity [24, 25].

In the experiment with double treatment of the liquid white and gray cast iron in the mold there has been studied the effect of different in functional purpose and impact on the melt additive combinations: graphitizing and carbide-stabilizing, nodularisation and carbide-regulating as well as nodularisation and graphitizing (Figure 2).

The results show that, in case of using both gray cast iron and white cast iron as an initial raw material, the efficiency of dual inmold melt treatment was higher in comparison with single treatment with only one additive. [26].

It is found that, for example, for improved wear resistance of castings made from the initial gray cast iron, the most effective is the double treatment first by carbide-forming additive with subsequent modification by nodularisation or graphitizing additive. To obtain high ductile properties of iron castings, made from the initial cast, prone to chill crystallization (WCI), effective is the dual treatment initially by doped nodularisation with subsequent graphitizing additive modification.

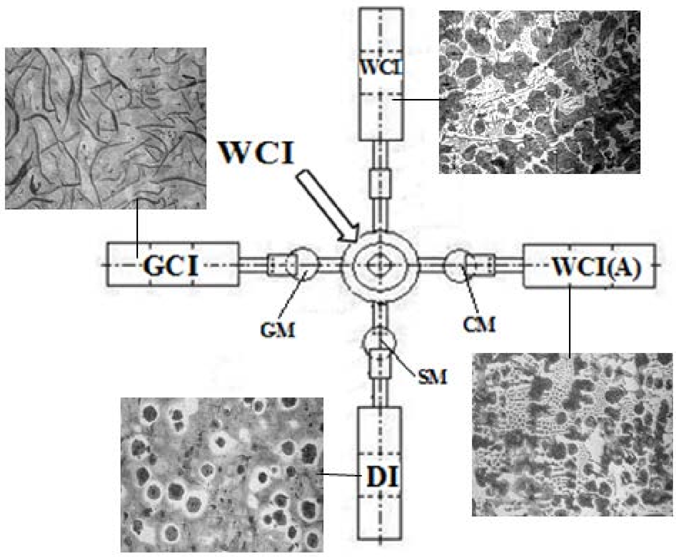
The next scope of using inmold inoculation can be the technology of obtaining from one source of iron, including the one in a common mold, of castings of different structure and properties [27], which is important for small foundries or repair sites using one melting unit and a large range of small and medium-sized castings of various irons.



SM – spheroidizing modifier, GM – graphitizing modifier, CM – carbide-regulating modifier, GCI – gray cast iron, WCI – white cast iron

Figure 2: Double-mold melt processing of gray (a, b) and white (c, d) iron

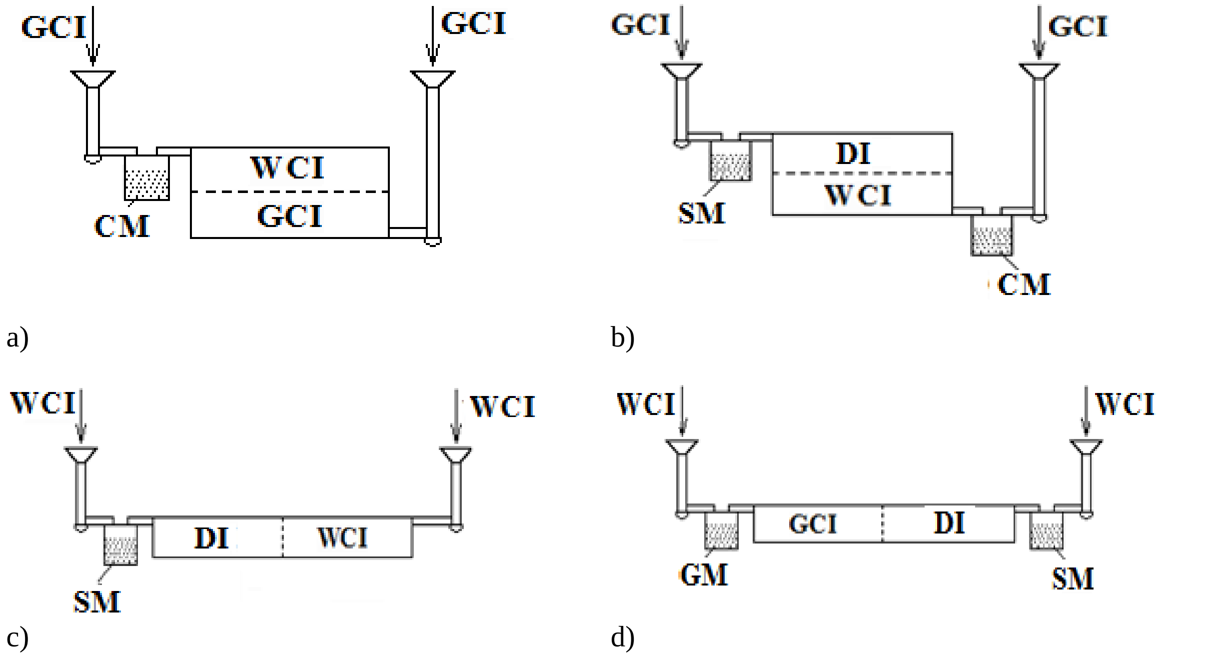
For example, taking iron as a starting melt, which tends to crystallize with the chill (WCI), placing an inoculant into a reaction chamber of one of the branches of the runner system, a spheroidizing modifier into a reaction chamber of another branch, a carbide-regulating additive into the reaction chamber of a third branch and using a fourth branch of the runner system without reaction chamber through which the cast metal will flow without any additional treatment (Figure 3), we obtained four castings respectively with the structure of white (WCI), further alloyed white cast iron (AWCI), gray with inclusions of flake graphite (GCI) and high-strength nodular cast iron (HCI) [28, 29].



WCI – white cast iron, WCI(A) – alloyed white cast iron, GCI – gray cast iron, DI – ductile iron, GM – graphitizing modifier, CM – carbide-regulatingy modifier, SM – spheroidizing modifier

Figure 3: Scheme for obtaining castings with different structures and properties in a single mold from one initial cast iron

Gray cast iron, when used as a starting melt, tends to crystallize with the evolution of free graphite, and treating it in the common mold by pouring various additives, placed in the flow of reaction chambers of individual runner systems, castings were also obtained with the structure of white, gray flake graphite and ductile cast iron with nodular graphite, each of which differs in hardness and other mechanical properties [30].
One of the advanced applications of the technology of inmold inoculation of the basic source of iron by heterogeneous by functional purpose modifiers or additives is to obtain castings with differentiated structure and properties in parts, different sections or individual surfaces [31, 32].
The idea of the proposed technology is that the casting is obtained by filling the mold cavity by a base molten gray cast iron source (GCI) or white cast iron (WCI) split into two streams, one of which is sent directly to one part of the mold cavity without any treatment and the second is firstly subjected to modifying treatment in the reaction chamber by a modifier, and then sent to another part of the mold cavity (see Fig. 4a, b). Also is possible the inmold processing of both streams of molten iron in the reaction chambers of the gating system by different by functional purpose and effect modifiers or other additives (Figure 4, b, d) [32-36].

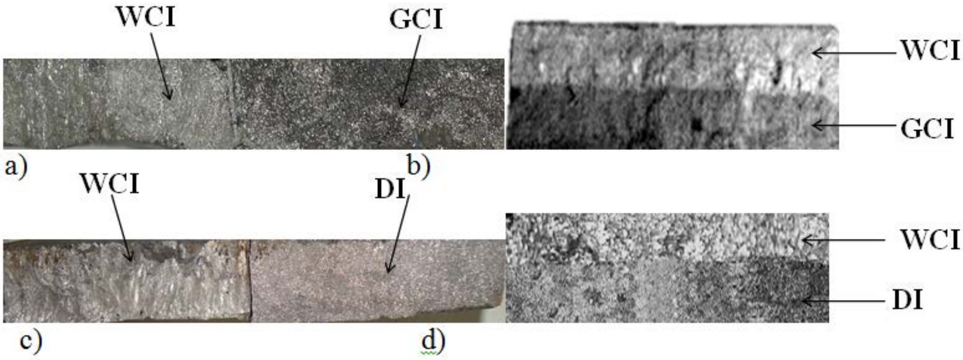


WCI – white cast iron, WCI (A) – alloyed white cast iron, GCI – gray cast iron, DI – ductile iron with nodular graphite, GM – graphitizing modifier, CM – carbide-regulatingy modifier, SM – spheroidizing modifier

Figure 4: Scheme of obtaining two-layer (a, b) and bilateral (c, d) castings with differentiated structure and properties using the technology of inmold inoculation

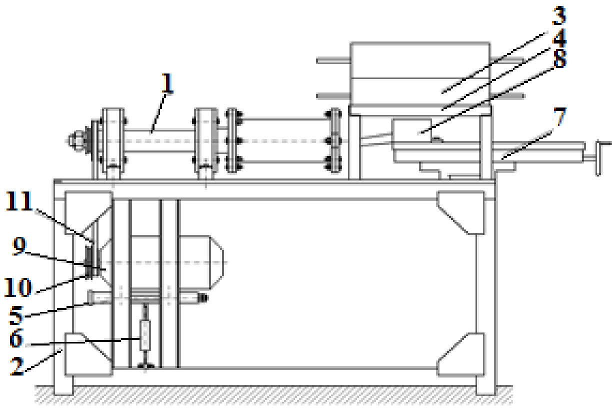
As a result of numerous laboratory and industrial tests the feasibility of this technology is confirmed, and two-sided double-layer horizontal plates with a combination of structure and properties of solid iron with carbides of white cast iron in one piece and gray flake graphite (Figure 5, a) or high spheroidal graphite iron castings in another part are obtained (5b).
Of great interest is the application of inmold inoculation method for the production of castings with differentiated structure and properties of the outer and inner layers by centrifugal casting.
In practice, centrifugal castings (blanks) are obtained by sequential pouring into a rotating mold after a certain period of time of specified portions of different chemical composition of molten metal melted in different melting aggregates, which is a serious lack of technology and complexity and makes it a more costly process of manufacturing such castings and requires precise synchronization processes for the preparation of heterogeneous melts and filling them into a rotating mold [37, 38].
In order to eliminate these drawbacks we have proposed a technology for producing two-layer or multi-layer centrifugal parts out of a single initial melt with the structure and properties of solid wear-

resistant outer layer of the white cast iron and ductile cast iron in the shock-resistant mounting of the inner layer of the casting [39-41].



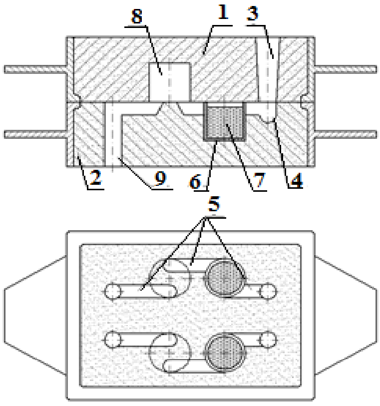
GCI– gray cast iron, WCI– white cast iron, DI– ductile cast iron with nodular graphite
Figure 5: Fractures of bilateral (a, c) and double-layer (b, d) castings

For testing the new technology there has been designed and manufactured a spindle centrifugal casting plant with horizontal axis of mold rotation, allowing a two-layer or multi-layer molded articles with differentiated structure and properties of materials in the different layers from the same source of molten iron (Figure 6). [42]



1 – centrifugal device; 2 – frame; 3 – fillingand modifying device; 4 – frame of the filling and modifying device; 5 – sub-plate; 6 – tensioner; 7 – bed; 8 – casting bowl; 9 – engine; 10 – drive pulley; 11 – belt.
Figure 6: Schematic of the laboratory setup for centrifugal casting for the production of castings with diverse properties forinmold inoculation

A special feature of the designed and manufactured installation for centrifugal casting is the presence in its design of a special filling-modifying device (block, module) 3, in which the inmold processing of individual batches of a melt, flow metering and regulation of the melt inflow rate into the mold (Figure 6).
The filling and modifying unit (module) is a disposable or semi-permanent mold, which is located in front of the rotating casting mold over the shot sleeve moving along the longitudinal axis of the mold and provides an opportunity to carry out during casting the initial melt processing by modifiers different by purpose and impact on the structure and properties, placed in a flow-through reaction chambers of the autonomous gating systems of the mold (Figure 7) [43,44].



1 – upper half-mold; 2 – lower half-mold; 3 – riser; 4 – sump; 5 – horizontal channels; 6 – reaction chamber; 7 – modifier; 8 –slag trap;9 – vertical output channel.
Figure 7: Scheme of the filling and modifying device

The number of independent gating systems is determined by the number of layers with differentiated structure and properties to be obtained in a centrifugally cast product. Thus, in all or in a part of the independent gating systems are provided intermediate running reaction chambers (item 6 in Fig. 7) in which on the path of the melt when pouring modifiers 7 are placed for inmold treatment of the melt portions moving through the corresponding runner system by chute into the rotating mold (Fig. 7).
As a result of numerous experiments there was confirmed the feasibility of the proposed technology, perfected the time-temperature regimes of two-layer castings with differentiated structure and properties from a single initial melt. The research results were used for obtaining bilayer industrial castings "Cartridge" of 250 mm in length and of 100 mm in diameter with a combination of the structure and properties of white iron in the outer layer and gray iron with lamellar graphite or nodular iron with spheroidal graphite in the inner layer [45].
The proposed technology of inmold melt processing are protected by patents of Ukraine and may become promising for introduction into industrial practice in order to solve complex problems of improvement the quality and properties of castings of wide application, as well as increasing the technical and economic factors of production.

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