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# CHANGING THE PARAMETERS OF THE QUARTZITE CRYSTAL LATTICE FOR ENSURING THE EFFICIENCY OF CARBURIZING SYNTHETIC CAST IRON

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**ABSTRACT**

One of the ways to reduce the cost of casting is to smelt pig iron on a cheap stock, that is, to replace expensive foundry-iron and steel-making iron with steel scrap with its further carbonization. Steel waste is basically much better than foundry-iron and steel-making iron in terms of materials, free from harmful impurities and inclusions. The absence of free carbon in the metal stock makes it possible to obtain any of its content in synthetic iron affecting the structure and properties of cast iron. The process of metal carbonization is the most significant stage in the production of synthetic iron. It largely determines the structure and quality of castings. Therefore, it is very important to study the patterns of dissolution of carbon in the melt. In the course of the study, there were established changes in the parameters of the crystal lattice of quartzite while it was drying using different temperature regimes. These changes further affect the lining resistance during the carburization of the melt. This is due to the fact that the production of synthetic iron from one steel scrap leads to a significant increase in the number of carbonizer (to 40 kg by 1 ton of the alloy), and forces the carbonizing process to proceed at elevated temperatures. For this reason, the sintered lining layer should consist of cristobalite, since it can withstand higher melting temperatures.

**Keywords:** sour lining, induction furnace, synthetic cast iron, steel scrap, carburizing.

## 1. INTRODUCTION

The process of dissolving carbon in iron melts has great practical importance due to the wide distribution of so-called "synthetic" pig iron. Production of castings from synthetic irons that were smelted using an increased amount of steel scrap in the stock using induction melting furnaces of industrial frequency (ICT) proved to be economically and environmentally beneficial. However, in the process of melting cheap steel waste it is required to substantially increase the carbon content in the melt. For this reason, the carbonization of molten metal is one of the main processes of their smelting.

In the domestic practice of foundry production, carbonaceous or carbon-containing materials are used as carriers of carbon. Those can be artificial: coal coke, charcoal, graphite of various grades; and also, those can be natural: natural or flake graphite, various coals including anthracite and heat-treated anthracite or thermoanthracite. At the same time, regulatory documentation with the requirements that the carbonizer must meet is usually absent. Most often, when selecting a carbonizer, the quality of the material is judged by the regulated content of carbon in it, and by carbon absorption from the melt. A comparative analysis of the efficiency of the interaction of the melt with carbon materials is carried out in the literature, without taking into account the peculiarities of their micro composition and microstructure. For this reason, the influence of ash on the carbonizing process cannot be ignored, since it can affect the carbon absorption by the melt as a result of slowing down of molecular diffusion. Ash impurities, for example, in anthracite are mainly in the form of interlayers in the intergranular space. Pushing the plane of the crystallites and simultaneously stitching them, they nevertheless reduce the bond strength of the crystallites between themselves. It is mineral impurities that first react with the melt, pushing the actual carbonization process in time.

Electrode strikes, graphite chips, coke breeze, coal granules, etc. are used as carbonizers. Reducing the size of the carbonizer grains increases the contact surface of the carbonizer with metal and accelerates the process, but if the carbonizer particles are too small, their carryover increases with ascending airflows and pollution atmosphere at the smelting site. It is practically established that the optimum size of the carbonizer particles is 3 ... 6 mm. The main part of the carbonizer is set together with the stock to the bottom of the tub under a layer of steel scrap. When an electrode strike is introduced into the melt, its absorption is 80–85%.

## 2. CARBONIZING IN THE SMELTING OF SYNTHETIC PIG IRON

The carbonization efficiency depends on the melting conditions, the chemical composition of the metal, the intensity of the melt mixing, the temperature of the melt. Table-1 shows the data for ICT10 obtained in 1970 [1]. It follows from them that the degree of saturation of the metal with carbon is higher, the more purely in chemical composition the material is and the less ash content it has.

To date, the best carbonizer is artificially ground brand A graphite, produced by LLC SPE "GrafitPro", Chelyabinsk. It contains the maximum amount of carbon and the minimum amount of ash.

The optimal carbonization rate is achieved at 1400-1470 °C and is 0.12% / min. When carbonizing, the melt temperature is lowered by 50 °C for every 1% of the carbon absorbed. When smelting synthetic iron in the ICT furnace 1, with preservation of the “swamp” in the amount of 300 kg, using cold pig iron and scrap iron, no more than 30% of steel scrap (300-350 kg) was allowed to be used. Based on this, it is necessary to increase the carbon content by 1.3%, which will take 10-15 minutes, during which the temperature of the metal will fall by 60-70 °C, which does not affect the lining durability.

**Table-1.** Comparative data on the use of various carbonizers in the smelting of synthetic pig iron using 30% steel scrap.

| Carburizer | Content, % | | Carbon absorption parameters | | | Note |
|---|---|---|---|---|---|---|
| | Carbon | Ash | Carburizing time, min | Carbon learning, % | Assimilation speed of Carbon, % $C \cdot min^{-1}$ | |
| Donetsk coal | 83,4 | 18,6 | 24 | 60 | 0,063 | Reference [1] |
| Metallurgical coke | 96,5 | 11,7 | 23 | 75 | 0.080 | Reference [1] |
| Crystalline graphite | 91,0 | 8,5 | 23 | 77 | 0,083 | Reference [1] |
| Electrode strike 1 | 90,9 | 2.8 | 19 | 90 | 0,100 | Reference [1] |
| Electrode strike 2 | 97,0 | 1.2 | 22 | 95,1 | 0,132 | Reference [1] |
| Electrode powder | 92,8 | 2.3 | 27 | 93 | 0,120 | Reference [1] |
| Artificial graphite milled grade A | 99 | 1.0 | 20 | 85 | 0,136 | TU 1916-109-71-2000 |
| Pitch coke | 97 | 0,5 | 19 | 80 | 0,104 | GOST 3213-91 |
| Low-sulfur coke | 94 | 1,0 | 21 | 80 | 0,110 | GOST 22898-78 |
| Electrode strike | 98,0 | 1,0 | 20 | 90 | 0,130 | TU 1911-109-73-2000 |
| Strike of blocks | 95,0 | 3,0 | 34 | 85 | 0,985 | TU 48-20-86-81 |

However, since 2000, iron scrap on the secondary market bases has disappeared and it has become impossible to use the traditional metal mill. It was possible to increase the share of cold pig iron to 70%, but this led to a rise in the cost of the alloy, and accordingly, castings by 10%, which made them uncompetitive.

For these reasons, they began to use a metal mill, consisting of 70-88% of steel scrap and increase the initial temperature for carrying out high-quality carbonizing by 100-150 °C, as its amount increases by 3-4 times. Such metal mill was also used abroad [2]. The problem of carbonizing the smelting of such synthetic iron is also reflected in [3]. This dramatically affected the durability of the acidic lining.

Therefore, in the last century it was found that a temperature rise of 100 °C above 1450 °C leads to a decrease in resistance from 350 to 180-200 melts [4].
The reason for this is the acceleration of the reaction:

$SiO2 + 2C \rightarrow Si + 2CO \uparrow$, which causes rapid destruction (dissolution) of the lining.

This leads to an increase in downtime associated with the furnace re-fitting, waste of materials and energy and, ultimately, to a decrease in production efficiency. The use of other materials for lining leads to costs increasing and does not provide such resistance.

For this reason, research is still being conducted, that is aimed at finding ways and methods to ensure the high durability of the acidic lining.

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## 3. EXPERIMENTAL STUDY

In the presented research, the work was aimed at studying the state of the parameters of the quartzite crystal lattice during all technological operations related to its preparation, preparation of the lining mass, manufacturing of the lining, its sintering, and conducting a melting campaign.

### 3.1 Detection of changes in the parameters of the lattice during drying

The characteristic temperature points of polymorphic transformations in quartzite, according to previous studies of scientists from different countries, are: 117 °C, 270 °C, 573 °C, 1025 °C, and 1470 °C. With proper exploitation of an induction crucible furnace for smelting pig iron, it is also necessary to know how the lining will work at the following temperatures:

a) 1550 °C is the temperature at which the lining is aged at the end of its sintering process;
b) 1570-1650 °C is the alloy carburizing temperature;
c) 1450-1470 °C is the metal discharge temperature, which depends on its grade;
d) 1000-1050 °C is the temperature of the cooling furnace at the release of the first batch of metal, without adding new batches;
e) 800-900 °C is the temperature of lining cooling when metal is drained and loaded with a new portion of the stock.

At the first stage, a study was conducted on the changes in the parameters of the quartzite crystal lattice during its drying by the method of X-ray fluorescence analysis using a BRUKER D8 ADVANCE X-ray diffractometer with Bragg-Brentano focusing optics. A HTK 16 high-temperature camera was used to carry out temperature experiments on the diffractometer. An X-ray tube with a copper anode was used, the diffraction spectrum was recorded with a VNNTEC-1 high-speed position-sensitive detector.

It was learned that during the traditional heat treatment to remove moisture (heating to 800 °C and aging for 2 hours) there were changes in quartzite that were not previously noticed (Figure-1).

It was established that there was a shift of the angle of the interplanar distances 2-Theta ° to the right and in the interval of the angle 2Θ = 20.419-59.859 it was 6.6% relative to the original.

When changing the temperature of the drying of quartzite (heating to 2000 °C and aging for 2 hours), such changes were not observed (Figure-2) [5].

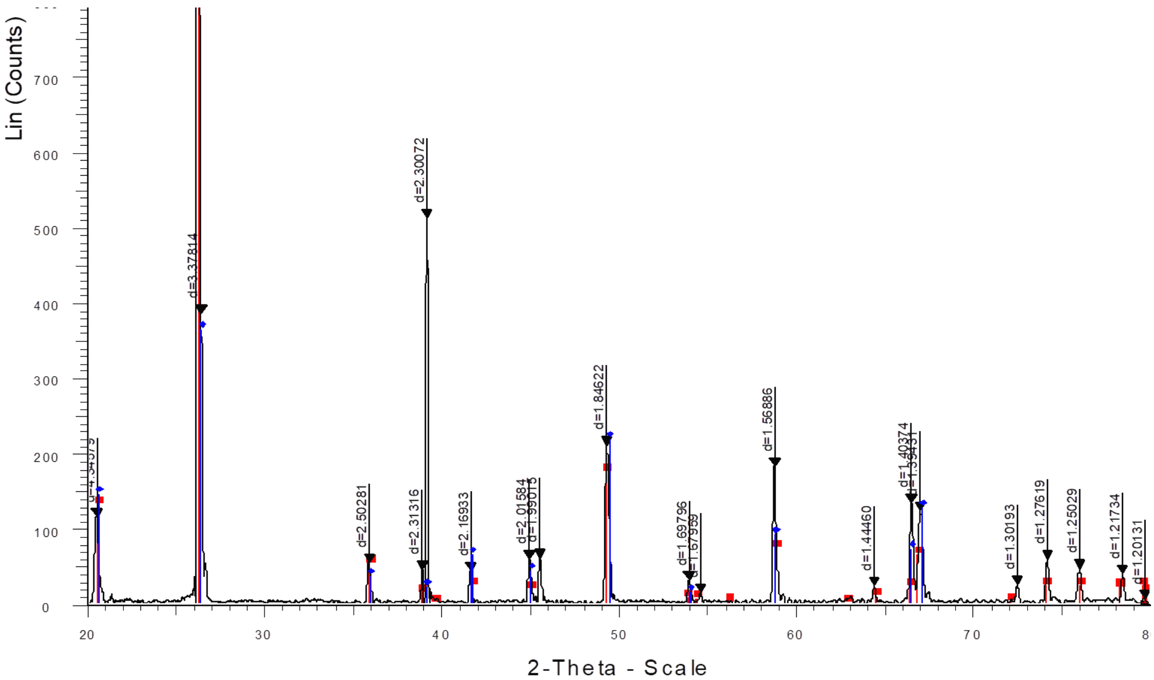


**Figure-1.** Diffractogram of cooled quartzite, taken at a temperature of 30 °C: ■ is quartzite; d presents interplanar distance, Á.

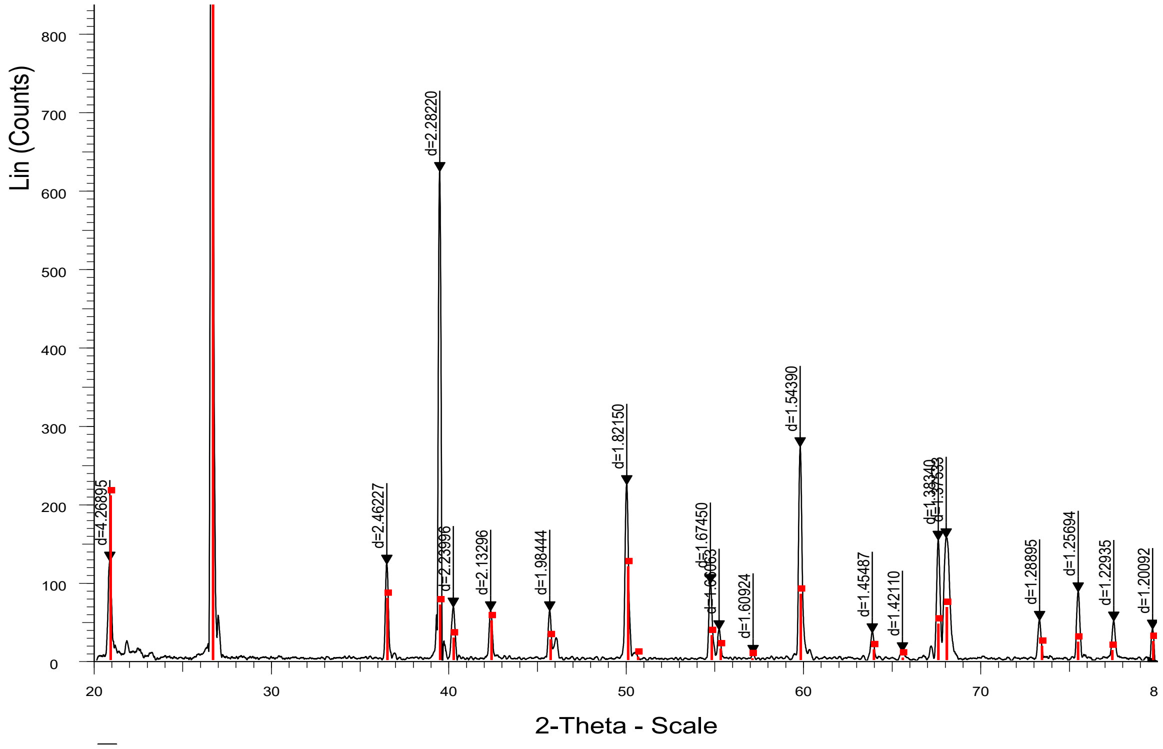


**Figure-2.** Quartzite diffraction taken on cooling to 30 °C. ■ is quartzite; d presents interplanar distance, Å.

Since the shift of the interplanar spacing angle 2-Theta ° to the right in the interval of the angle 2Θ = 20.419-59.859 was established for the first time, it was decided to conduct a study of this process using a thermal method using the NETZSCH STA 449C Jupiter at a heating rate of 10 K / min. The collection rate of points was 100 t / min. For the measurements, two crucibles were used, one of which was used to place the test sample, the other crucible was used as the standard. Experimental studies were performed in corundum crucibles.

As a result, a derivatogram shown in Figure-3 was obtained.

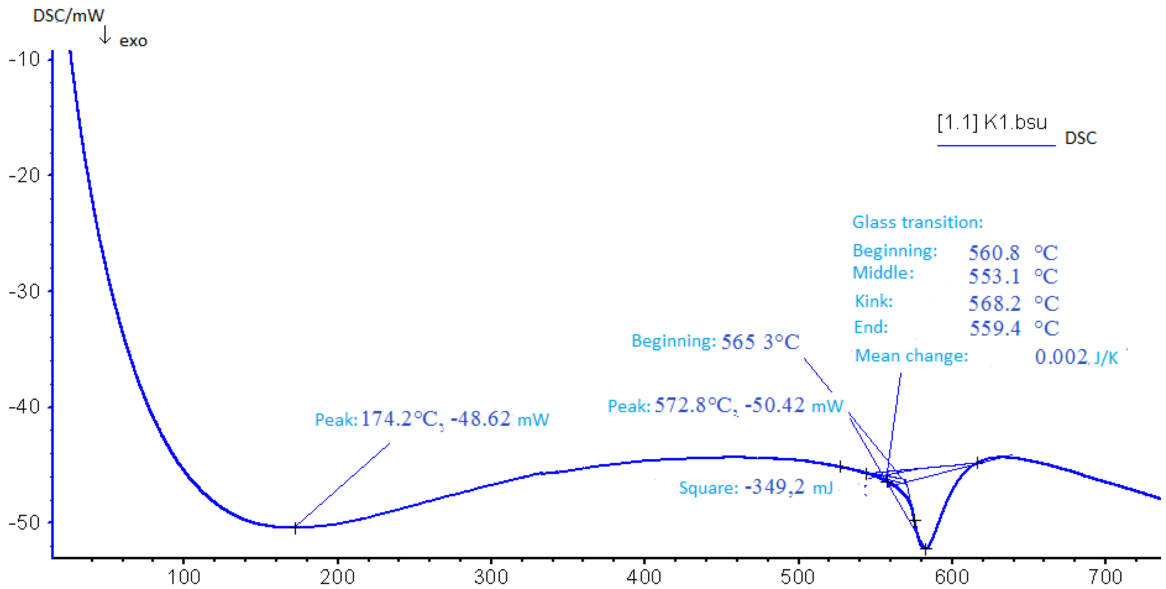


**Figure-3.** Derivatogram of quartzite, subjected to heating at 800 °C and aging for 2 hours.

At a temperature of 570 °C, a fairly intensive phase transformation with the release of heat occurred. It is characterized on the derivatogram with the peak area the thermal effect of the formation of a new phase (enthalpy) numerically equal to (-349.2 mJ). The process of phase transformation is accompanied by the appearance of a more discharged aggregate state (an increase in volume and a decrease in density due to the expansion of the

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crystal lattice). Therefore, the effect of a change in the crystal lattice is confirmed [6].

With low-temperature processing, consisting in heating to 200 °C and aging for 4 hours, there is no such change (Figure-4).

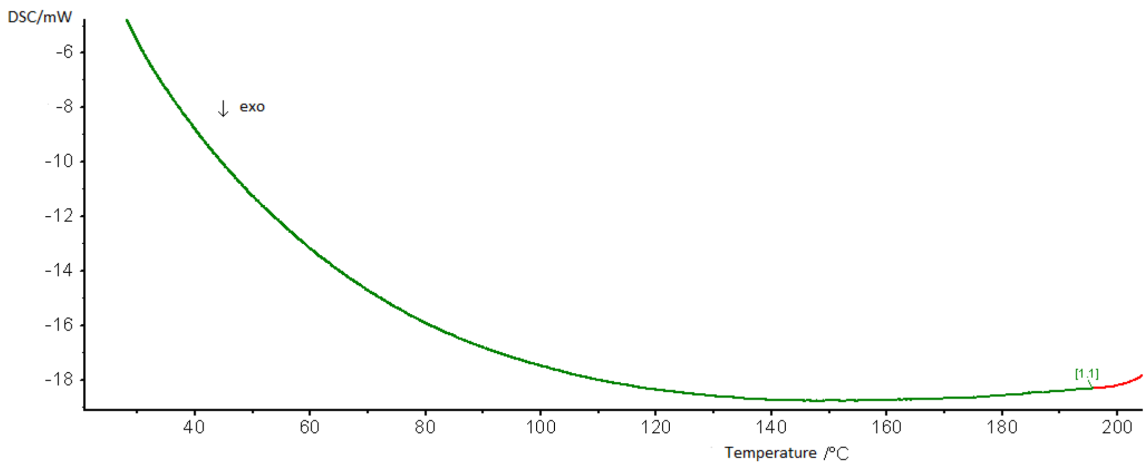


**Figure-4.** Derivatogram of quartzite, subjected to heating at 200° C and aging for 4 hours.

**3.2 Detection of changes in lattice parameters after sintering mode**

After drying and cooling the quartzite, a lining mass is prepared in production, in accordance with the generally accepted technology, it is also packed and sintered according to a special schedule. Sintering ends with the temperature reaching 1500-1550 °C. Further begins commercial operation of the crucible furnace.

The temperature scenario of sintering, from the very beginning of the use of DTI furnaces, was intended to obtain three zones in the lining, because each layer should consist of a specific phase composition:

a) a loose layer of quartzite mixed with boric acid;
b) half-sintered tridymite and quartzite;
c) sintered from cristobalite and tridymite.

Figure-5 shows the layout of the zones of quartzite lining in the DTI furnace.

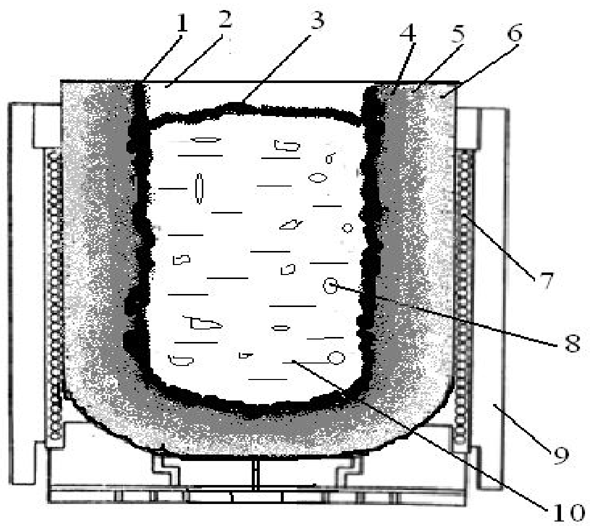


**Figure-5.** Layout of zones of quartzite lining in DTI furnace: 1 - slagged sintered lining crust existing at a temperature of less than 1200 °C, 2 - gas phase of the furnace, 3 - liquid slag on the surface of the melt, 4 - sintered lining zone, 5 - half-sintered lining zone, 6 - zone of unbroken mass (buffer), 7 - furnace inductor, 8 - gas contained in the melt itself, 9 - furnace body, 10 - melt.

It turned out that such a layer distribution scheme occurs only with heating to 800 °C, followed by soaking. It was believed that the preparation of the tridimite phase gives the lining a higher durability, which was confirmed by the use of a metal mill, consisting of foundry-iron scrap and steel scrap [7]. In this case, the smelting was conducted at temperatures not higher than 1470 °C. A complete transition to steel scrap, which resulted in the use of a significant amount of a carburizer (3-4 times higher), led to an increase in the temperature scenarios of smelting to 1570-1650 °C. This is noted in [8].

## 4. RESULTS

On this basis, the cristobalite phase becomes more attractive, as it can withstand higher melting temperatures. Studies have found that such a phase can be obtained (bypassing tridymite) using quartzite drying at a temperature of 200°C and subsequent soaking (Figure-6).

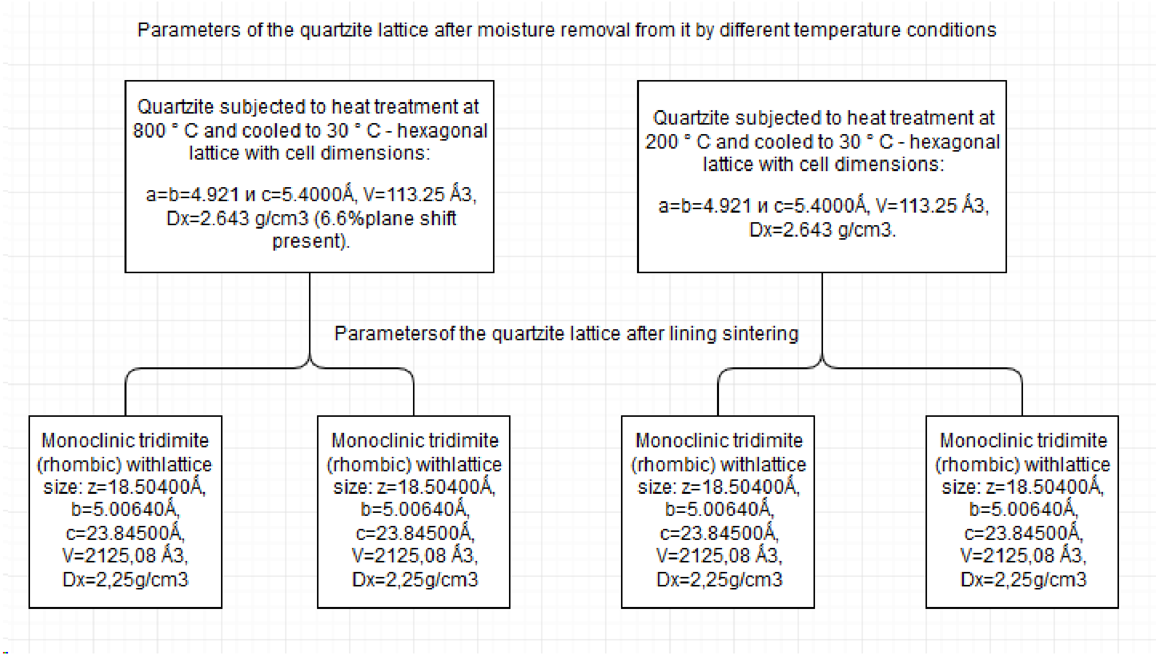


**Figure-6.** Diagram of the formation of quartzite phases during its drying and sintering.

## 5. CONCLUSIONS

Thus, the conducted studies allow us to conclude that by varying the temperature scenarios of quartzite processing, it is possible to obtain its phase state, which withstands higher temperatures, has a higher thermal resistance at operating melting temperatures of more than 1450 °C, which are necessary to carry out synthetic iron casting from steel metal mill [9,10].

Tridimite is stable at a temperature of 870-1470 °C, has a density of 2.23 g/cm3 and a hardness of 6.5 units on the Mohs scale.

Cubic cristobalite is stable at 1470-1715 °C and has a hardness of 7.25 units and a density of 2.27 g/cm2. Based on this, the sintered layer, which has a hardness higher by 11.5%, is more stable during the carburization process, since it is better able to withstand the active mixing of the surface layers of the melt in contact with it.

This makes it possible to use DTI furnaces for smelting not only synthetic iron from one steel scrap, but also special iron and steel [11,12].

In addition, the use of low-temperature processing of quartzite, in order to remove moisture, eliminates the high-temperature heating furnaces, heat-resistant steel, necessary for the manufacture of tanks, in which quartzite is dried. This leads to lower costs for materials, electricity and operating costs [13, 14].

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