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Influence Factors on Stress Distribution of Electric Furnace Roof

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Abstract: Electric furnace roof is an important device for electric steel making, whose heat preservation performance and life-span have a direct impact on the economic benefits of iron and steel enterprise. This paper investigates the effect between the stress level of electric furnace roof and the material parameters. Research indicates that they have a trend to change in the same direction. *Copyright © 2013 IFSA.*

Keywords: Electric furnace roof, Stress field, Finite element method, Influence factors.

1. Introduction

Electric furnace roof is an important part of electric arc furnace lining, the length of life of the furnace roof and thermal insulation performance has a very close relationship with indexes of technical and economic of steel production, quality and consumption. Domestic and foreign scholars on the furnace roof has taken many measures to reduce the production cost, enhance the thermal stability, such as improving the furnace roof material, improve the content of alumina brick, increase the camber of furnace roof and height of the furnace lid center to the weld pool surface, improvement of operation, using water-cooled furnace roof brick furnace roof. Although these measures have achieved some results, still failed to solve the those problem of refractory brick furnace roof that difficult installation, short service life, the water-cooled furnace roof heat loss and cannot meet the needs of development that electric arc furnace turn into large capacity and ultrahigh power. Therefore, it is the main factor of restricting steel benefit that the installation period, thermal insulation performance and the service life, which it has a crucial impact on productivity and economic benefits of the iron and steel enterprise. Therefore, how to shorten the furnace roof the installation period and improve its service life has become an important measure to reduce the production cost and enhance the competitiveness of steel making technology of electric arc furnace.

Taking a steel 30t EAF roof as the research object, research the regular that stress field, material properties and the preform shape impact on the furnace roof stress field, which the high aluminum brick furnace roof and precast furnace roof in typical working condition. To try compare high aluminum brick furnace roof with precast furnace roof in the stress level for the precast block furnace roof provides the theory support, and to give quantitative reference for casting scheme, finally provides the theory support for the production and promotion of precast block furnace roof, and then improve the iron and steel enterprise economic benefit. Therefore, the research has important significance in reducing the labor intensity of workers, decreasing the production cost and improving economic benefits [1].

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2. Established CAD/CAE Model of the Electric Furnace Roof

High alumina brick furnace roof is formed by moulded high aluminum brick, precast block electric furnace roof is made of fireproof material casting precast block in accordance with the principle of assemble building blocks together, although the manufacturing process is different, the shape and size are same. So during the CAD modeling process, based on a real geometry of a certain steel 30t electric roof (the 3D effect graph as shown in Fig. 1) to establish CAD model of all the furnace roof.

On the one hand and considering the real condition of the furnace roof structure and load, on the other hand, ignore the relatively small and does not affect the overall process, take the following hypothesis:

1) The geometric model are established according to Fig. 1, taking into account the thermal roof transfer between center roof and furnace roof, all models were established the complete model which including center roof and furnace roof. Its main dimensions: charging hole diameter is 150 mm, the electrode hole diameter is 250 mm, the circle diameter of electrode hole center is 900 mm, the upside surface of center roof diameter is 1730 mm and the downside surface diameter is 1606 mm, the turning diameter of the outer surface of furnace roof is 3218 mm and inner surface diameter is 3000 mm.

2) Due to the influence of the furnace roof geometry, it is difficult to cast the whole furnace roof, at the same time, according to the demand of the project, this paper set up only block furnace high aluminum brick furnace roof and precast furnace roof of three kinds of casting solutions, as shown in Fig. 2.

3) Due to the different fabrication process of two kinds of furnace roof, the high aluminum furnace roof is a block and closed automatically, there is no interface inside, but precast furnace roof has interface in it, because it is composed by several block. So adopt different Boolean operation for two kinds of furnace roof in the process of build CAD model. To adopt the GLUE operating for high aluminum furnace roof, make the center roof and the furnace roof bonded as a whole block, ensure the nodes coincided on physical interface when build the CAE model; for the precast furnace roof, set the VGEN command parameters according to the different number of precast block to guarantee the existence of the interface between the precast block, make a preparation for contact pair of precast blocks, at the same time, taking into account the furnace roof bottom from the molten steel and arc is close, the circumferential expansion is more than the radial expansion when it get thermal shock, ignoring the contact between precast block and the center roof, precast block and the center roof are all adopt the GLUE operation, eliminate joint surface, to ensure the nodes coincided of the precast block and the center roof on the interface.

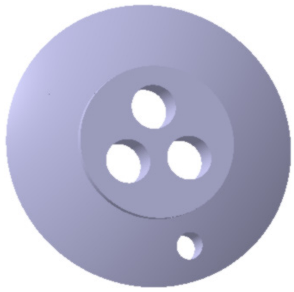


Fig. 1. The entity of electric furnace roof.

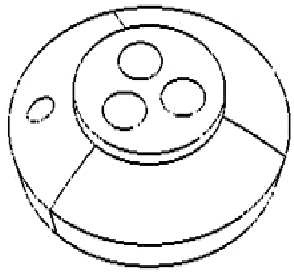
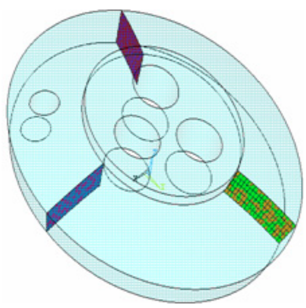
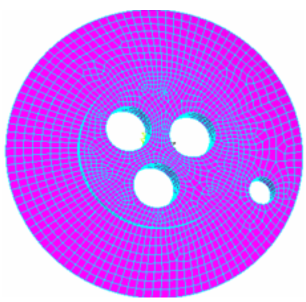


Fig. 2. CAD model of Precast block furnace roof (casting three).

After built CAD model, then to build CAE model, including definition the material parameter of electric furnace roof, selection element type and mesh control [11]. High alumina furnace roof and the precast furnace roof are made of refractory materials with different fabrication process, and its main components are AL_2O_3, so the material properties definition of the two model are same when build the CAE model, CAE model as shown in Fig. 3.



(a)



(b)

Fig. 3. CAE model and its contact pairs of precast block furnace roof (three blocks).

3. The Stress Field Analysis of Electric Furnace Roof

Only when the material's temperature changes, due to the external constraints and mutual constraints of each part internal, so that it cannot completely free expansion and contraction will lead to the generation of heat stress [12]. In the last stage of melting furnace roof under thermal shock is very strong, so it will produce thermal stress. In this chapter, a furnace roof temperature field as an initial condition, at the same time, carry out a boundary treatment of structure analysis on the furnace roof in need, make numerical simulation for the stress level and distribution.

Using the sequential coupling method when calculate stress field of the furnace roof [12], which is mean calculated model of the temperature e field at first, then regard the result of temperature field as body load to calculate stress field of it. This paper focuses on precast block of furnace roof whether can withstand temperature shock and not to burst damage, so when processing the stress analysis, just set the node temperature into the model as the body load [9], Considering the placement situation when assembling the furnace roof and the furnace body, and the locate function of bevel on furnace roof bottom with the cooling water pipe. The boundary condition and the load of stress analysis were treated as follows:

1) The last brick needs external force to push in when built the furnace roof with refractory brick;

2) Considering the furnace roof deadweight, acceleration of gravity was applied for all models in Z direction (MPA units in 9800);

3) All nodes that lie in bevel of the bottom of furnace roof were constrained under Descartes coordinates system, and ignore the function of drive, lifting, rotating on the furnace roof;

4) Reading the node temperature value of thermal analysis as the body loads of structural analysis.

Due to size and shape furnace roof will be changed with thermal shock; it should be according to the fourth strength theory to determine the stress level. The equivalent stress of ANSYS (Von Miss Stress) is calculated according to the fourth strength theory. So, after obtain the calculate destination file, draw the equivalent stress pattern of furnace roofs model in ANSYS universal post processor, to show that the variation of stress level in direction (thickness) of charging hole cross section, using ANSYS slice functions split each model along the center symmetry plane of feeding hole, to obtain the equivalent stress slicing image of each furnace roof model [2].

4. Analysis of Influence Factors on Stress Field of Furnace Roof

By the physics knowledge, material property model will directly affect the value of physical quantities, in view of the furnace roof model, the parameters of thermal physical properties and mechanical properties of furnace roof material have a direct impact on the temperature and stress levels of furnace, we can see from the basis of finite element theoretical, equivalent integral form of differential equations, that the geometry shape and structure of the model is direct impact solving domain and boundary conditions of physical field differential equation [3], and will also affect the distribution of physical quantity.

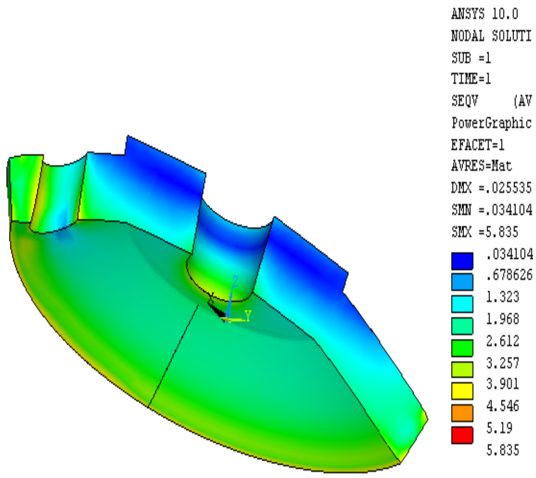


Fig. 4. Equivalent stress cloud chart of precast furnace roof (casting three).

1) Material parameters of the furnace roof

The furnace roof is made of high alumina materials with different manufacturing processes, and its finite element model contains only high aluminum material, so the thermal conductivity of high aluminum material directly affects the heat transfer matrix of furnace model, which will influence the temperature field of the furnace roof, the whole stiffness matrix of the furnace roof will be impacted by its elastic modulus and Poisson ratio directly, which will influence the stress field of the furnace roof, with using the material coefficient of thermal expansion to calculate the deformation by ANSYS, so high aluminum material coefficient of thermal expansion will also have a direct influence on stress.

For high alumina bricks, because of its raw material percentage of the quota has been standardized by industry regulations, once firing the kiln, its physical parameters had been identified, so the temperature field and stress field of high alumina brick furnace roof can be considered immutable, the castable is main of the high alumina raw material for precast casting furnace roof, adding MgO, Cr_2O_3, ZrO_2 powder at the same time, casting material coefficient of thermal conductivity, thermal expansion and elastic modulus can change with each component percentage changes, which indicates that the stress level of precast furnace roof can be controlled.

2) The structure of furnace roof

The relationship of geometric in internal structure of furnace roof has a large influence on the temperature field, which there is interface among the internal of prefabricated furnace roof and with high thermal resistance, which hindering the heat transfer. Therefore the temperature level of prefabricated furnace roof is lower than high temperature aluminum furnace roof. Electrode diameter size and set position, charging hole size and its location, the furnace roof thickness opening diameter and thickness will affect the temperature level distribution of furnace roof; the charging hole size directly affects the service life of the furnace roof, electrode diameter size and set the position, charging hole location directly affect the furnace roof stress levels and distribution. The direct correlation of the circumferential size furnace roof and production capacity has been standardized, so it can be concluded that the circumferential size of the furnace is not allowed to change for a certain production capacity, which can reduce the thickness of attempt, and carries on the temperature, stress analysis [4]. Limited to this paper, not for in-depth study, and compared to the influence of the material performance parameter, the size of the structure is relatively small.

Comprehensive consideration, casting material coefficient of thermal conductivity, thermal expansion coefficient and the elastic modulus of precast block furnace roof has a great influence on the stress field [5], and the law itself does not have special place, the similarities in their characteristics, at the same time, considering the effect that unit number for calculate time-consuming, make the following options:

1) in order to search the law which the physical parameter of casting material of precast furnace roof for its stress level, to cast three prefabricated furnace roof model as the research object without consider the high aluminum brick furnace roof.

2) Poisson's ratio is generally small changes, so just analysis the influence that the coefficient of thermal conductivity, heat expansion coefficient and elastic modulus on the furnace roof of the temperature field and stress field, without consider the structure dimensions.

4.1. Effect of Thermal Conductivity Coefficient on the Stress Field

The physical significance of coefficient of thermal conductivity is the quantity of heat conduction in the unit area in unit time when the unit thickness object has the unit temperature difference, which its numerical size has a relationship with the material composition, density, moisture content, temperature and so on [13]. When analysis the material parameters, we just set the coefficient of thermal conductivity from original 20 $W/(m \cdot K)$ to 10 $W/(m \cdot K)$ and 40 $W/(m \cdot K)$ respectively, the load and boundary conditions are set according to the above [6]. Run the L G. Mac, set the KX values were 10, 40 in the run windows of main macro file, twice calculation, then obtained the calculate result of coefficient of thermal conductivity which was set 10 $W/(m \cdot K)$ and 40 $W/(m \cdot K)$ respectively [10]. The furnace roof structure and loads, boundary conditions are not changed, so the material parameter change will only affect the numerical size of physical quantity, not affect the qualitative distribution; contact stress has little influence on the service life of the furnace roof [14], so this section and the following sections are not drawing the contact stress, only to draw equivalent stress of the a complete model, as shown in Fig. 5 and Fig. 6.

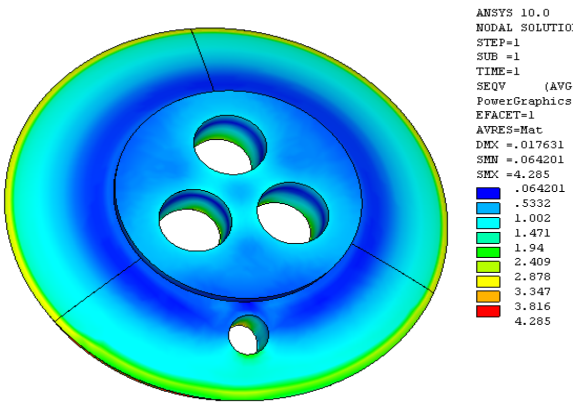


Fig. 5. Equivalent stress of furnace roof with thermal conductivity is 10 $W/(m \cdot K)$.

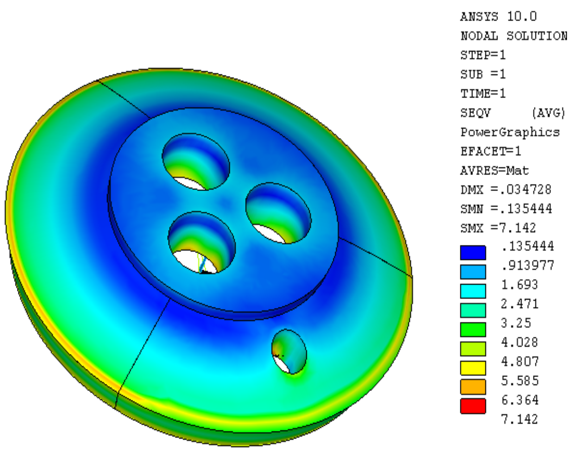


Fig. 6. Equivalent stress of furnace roof with thermal conductivity is 40 $W/(m \cdot K)$.

As you can see from Fig. 5, when the coefficient of thermal conductivity is 10 $W/(m \cdot K)$, the maximum equivalent stress is 4.285 MPa and minimum is 0.64 MPa of the furnace roof, most of the stress level in the 1.002 MPa - 2.409 MPa; it can be seen from Fig. 6, when the thermal conductivity is 40 W/(m•K), the maximum equivalent stress is 7.142 MPa and minimum is 0.135 MPa of a furnace roof, most of the stress levels in 1.693 MPa - 4.028 MPa.

As can be seen by comparing, the law of stress distribution did not change, but the stress level just increase and decrease as the coefficient of thermal conductivity, which means the furnace roof life will reduce with the increase coefficient of thermal conductivity. Therefore, the furnace roof stress have same change rules with the coefficient of thermal conductivity and the service life have reverse change rules with thermal conductivity change.

To sum up, the stress level of the furnace roof has same change rule with the thermal conductivity; heat insulation performance and the service life of the furnace roof has reverse change rule with thermal conductivity.

4.2. Effect of Thermal Expansion Coefficient on the Stress Field

For different material, the thermal expansion coefficients of each are not identical, and their numerical has a relationship with the actual temperature and reference temperature which determine their baseline length [7]. Reference temperature is 30 °C of thermal expansion coefficient for high alumina material, which the casting material is main of alumina and adding other alloy powder, so it is belongs to the composite material. According to the materials science, the thermal expansion coefficient of the composite varies with the different proportion of each phase.

In the same material parameters and load conditions, the thermal expansion coefficient values were modified by 7.3E-9 for 3.65E-9, 14.6E-9, ALPX were set 3.65E-9 and 14.6E-9 in the run windows of main macro file two calculation in the main macro file operation window. Due to the thermal expansion coefficient has no influence on the temperature level, so just considerate the change of furnace roof stress level. The equivalent stress of the furnace roof under the two kinds of thermal expansion coefficient was shown in Fig. 7 and Fig. 8.

As you can see from Fig. 7, in other conditions are unchanged, and only change the coefficient of thermal expansion for casting material, the value is reduced from 7.3E-9 K^{-1} to 3.65E-9 K^{-1}, the maximum stress is 2.725 MPa, the minimum stress is 0.01 MPa for furnace roof, most of the stress level in the 0.613 MPa - 1.518 MPa; it can be seen from Fig. 8, when the casting material coefficient of thermal expansion is 14.6E-9 K^{-1}, the maximum stress is 10.795 MPa and the minimum is 0.126 MPa of furnace roof, most of the stress levels in 2.497 MPa - 6.053 MPa.

As can be seen by comparing, the change of thermal expansion coefficient does not affect the overall stress distribution, in the feeding hole wall, there are still stress concentration; but the stress level as change with the thermal expansion coefficient, which means the equivalent stress of furnace roof at any point as increase or decrease with thermal expansion coefficient, by the fourth strength theory that the service life of furnace roof is decreases with the increase of stress level.

To sum up, the stress level of the furnace roof has same change rule with the coefficient of thermal expansion, and the service life of the furnace roof has reverse change rule with coefficient of thermal expansion.

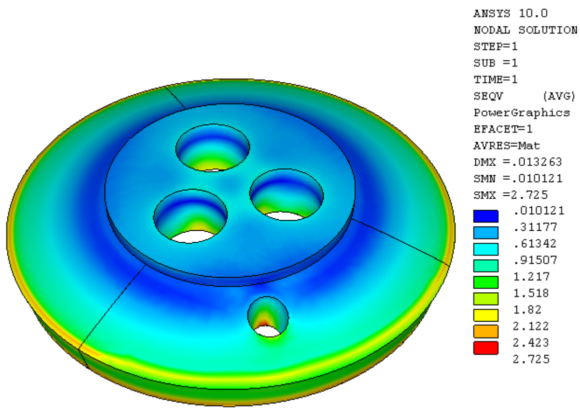


Fig. 7. The equivalent stress of the furnace roof in heat expansion coefficient is 3.65E-9 K^{-1}.

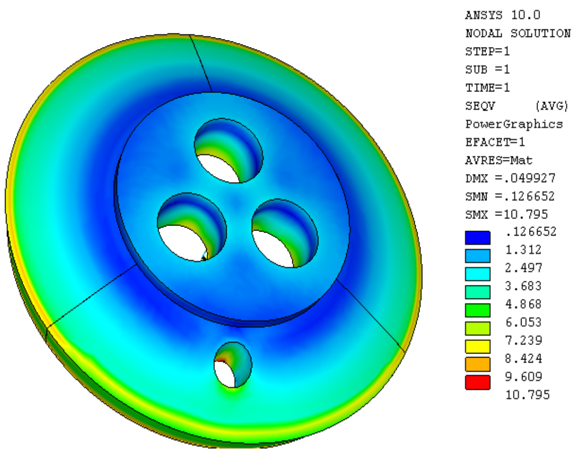


Fig. 8. The equivalent stress of the furnace roof in heat expansion coefficient is 14.6E-9 K^{-1}.

4.3. Effect of Elastic Modulus on the Stress Field

The material in the elastic deformation stage, the stress and strain are proportional to (obey Hooke's law), the coefficient of proportionality is called elastic modulus. Modulus of elasticity can be regarded as a measure of the difficulty degree of material produce elastic deformation, which its value is bigger, stress is also larger which makes the material produce elastic deformation, namely the material the greater stiffness, which in a certain stress, elastic deformation is small. Under without changing the other parameters and load conditions, the elastic modulus is changed from 2.63E5 MPa to 2E5 MPa and 8E5 MPa. In the main macro file operation window set the EX values for 2E5, 8E5 to calculate, obtain the equivalent stress of furnace roof, as shown in Fig. 9 and Fig. 10 respectively.

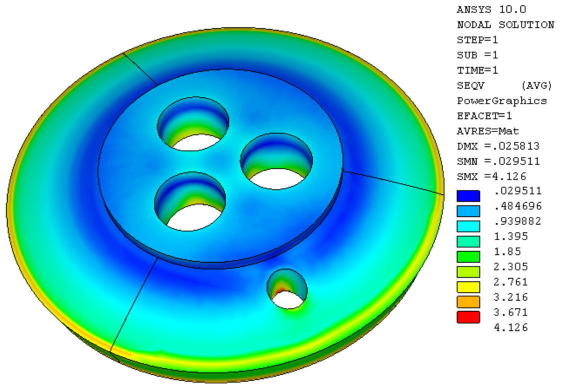


Fig. 9. Equivalent stress of furnace roof with the elastic modulus is 2E5 MPa.

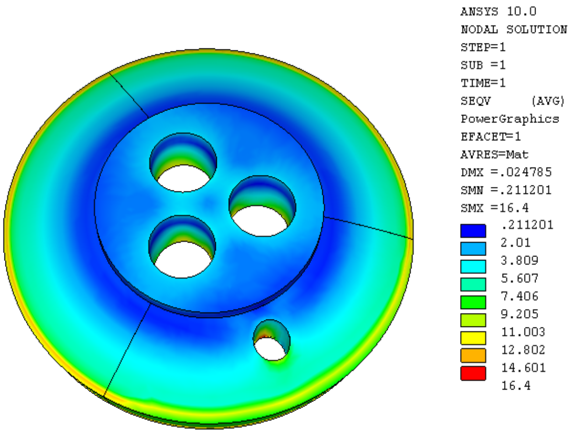


Fig. 10. Equivalent stress of furnace roof with the elastic modulus is 8E5 MPa.

As you can see from Fig. 9, in the other conditions remain unchanged, as the elastic modulus of the casting material is 2E5 MPa, the maximum stress is 4.126 MPa and the minimum is 0.029 MPa of furnace roof, most of the stress level of furnace roof is 0.939 MPa - 2.305 MPa; it can be seen from Fig. 10, casting modulus of elasticity material is 8E5 MPa [8], the overall stress level of furnace roof increases, the maximum stress is 16.4 MPa and the minimum is 0.211 MPa of furnace roof, most of the stress level of furnace roof is 3.809 MPa~9.205 MPa.

As can be seen by comparing, the changes in elastic modulus leads equivalent stress level at the same position of the furnace roof also changes in the same direction, and the service life of the furnace roof changes inversely with the modulus of elasticity.

To sum up, the lid of the stress level and the coefficient of thermal conductivity, thermal expansion coefficient and elastic modulus were in the same change direction, but the service life of the furnace roof and the coefficient of thermal conductivity, thermal expansion coefficient and elastic modulus changes showed the reverse.

The statistics which thermal conductivity, thermal expansion coefficient and the elastic modulus influence on the equivalent stress level of furnace roof as shown in Table 1, casting material performance parameters are conversion value which the value convert with the MPA unit system in the international system units.

5. Summary

There are many practical factors to affect the stress field of the furnace roof: the structure has impact on maximum stress level of furnace roof and contact stress among prefabrications. The law which the physical parameter of casting material of precast furnace roof for its stress level was analyzed, which is the thermal conductivity, heat expansion coefficient and elastic modulus of precast material. The results show that: the stress level of prefabricated furnace and the thermal conductivity coefficient, coefficient of thermal expansion and elastic modulus of cast material have same change rule, the insulation thermal performance of prefabricated furnace roof has the reverse change rule with the conductivity properties of the casting material, the service life of the prefabricated furnace roof has the reverse change rule with casting material in coefficient of thermal conductivity, thermal expansion coefficient and elastic modulus change reverse.

Table 1. The influence of casting material properties on the equivalent stress level of furnace roof (MPa).

Stress	Thermal conductivity, W / (m•K)		Thermal expansion coefficient, K^{-1}		Elastic modulus, MPa	
	10	40	3.65E-9	14.6E-9	2E5	8E5
Maximum	4.285	7.142	2.725	1.795	4.126	16.4
Minimum	0.064	0.135	0.01	0.126	0.029	0.211
Mean	1.002-2.409	1.693-4.028	0.613-1.518	2.497-6.053	0.939-2.305	3.809-9.205

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