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Comparative Analysis of the Parameters of Spherical and Relo Body Balls for Drum Mills

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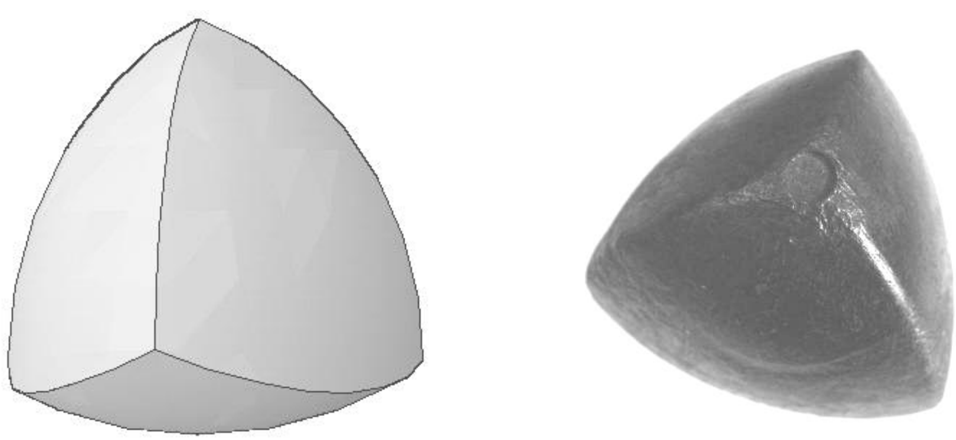
Abstract **-** In this paper a new type of grinding media – Relo body is presented. The geometrical and metallurgical parameters of Relo body and spherical balls are analyzed and compared with respect to comminution productivity. As a result, the following advantages of Relo body ball are determined: larger surface of the grinding media in the mill, which increase the attrition performance in comminution; arrangement of balls in the mill reduces the occupied by them volume; due to greater contact spot of the spherical side is improved the conditions for comminution; because of different cooling rate the volume with greater hardness after quenching is 61 % bigger (for 80 mm ball) then for corresponding spherical ball.

Keywords**:** Grinding media, Drum mill, Ball mill, Comminution.

1. Introduction

With Relo body term (Tsotsorkov at al., 2012) we denote the ball for drum mill which shape is similar to Relo tetrahedron –fig.1. This type of balls is an innovative grinding media compared with spherical balls (Penchev, Bodurov, 2013), which are used in the comminution of minerals and clinker. It



a) b)

Fig.1 [1]. a – Relo tetrahedron; b – die forged Relo body ball is shown in (Tsotsorkov at al., 2010) that in cooper ore grinding the productivity of ball mill is 8,5 % higher for class 0.080 mm using Relo body balls instead spherical balls.

All this shows that after many attempts to find a grinding bodies shape with greater performance then the spherical balls (Norris, 1954), (von Kruger at al., 2000), the use of Reloe body could lead to improving the productivity, energy and environmental efficiency of the drum mills.

Due to unconventional shape of the Relo body ball it is necessary to conduct systematic theoretical and experimental studies on the effect of the application of this new type of grinding bodies. This article presented the results of a comparative analysis of the parameters of spherical and Relo body balls.

2. Geometry

The spherical grinding ball has only one geometrical element – sphere with radius R_{SPH} . As seen on Fig.1 the geometric shape "tetrahedron of Reuleaux", and the similar Relo body ball are made of 14 elements – 4 faces - parts of spherical surfaces, 4 vertices and 6 edges. In (Penchev, Bodurov, 2013) is shown that the radius R_{RB} of Relo body spherical surfaces is 2.1487 times bigger then the radius R_{SPH} of the sphere with the same volume, i.e.

$$R_{RB} = 2.1487 R_{SPH} \tag{1}$$

It is shown also in this paper that the surface of a Relo tetrahedron is 9,35% greater than the surface of a sphere having the same volume. Depending on the manufacturing technology the surface of Relo body S_{RB} is greater then the surface of the relevant sphere S_{SPH} as follows

die forged ball: $S_{RB} = 1.09 S_{SPH}$

casted ball: $S_{RB} = (1.08 \div 1.085) S_{SPH}$ (2)

rolled ball: $S_{RB} = 1.075 S_{SPH}$

Table 1. shows the difference between the circumferential surfaces for one ton Relo body balls and according spherical balls. It is shown that for mill 4.5 x 6 m with 150 tons of balls the difference of surface is (514 - 74) m^2 depending on ball diameter. This means that when using Relo body balls the performance of drum mill by attrition (cascading regime) will be greater due to the greater size of the contact area of these balls in comparison with the same quantity of spherical balls.

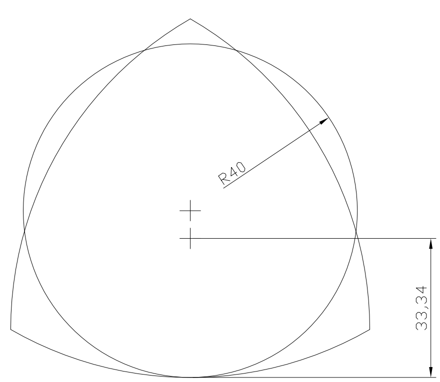


Fig 2. A section of a Relo tetrahedron with a sphere of equal volumes

In fig.2 are presented sections of sphere and Relo tetrahedron of the same volume. It is seen that the centre of gravity of Relo tetrahedron is below the centre of gravity of the according sphere.

Table 1. Difference between the surface of Relo body balls and according spherical balls. Both ball types are die forged.

Spherical surface radius, mm		One ball surface, sm^2		Surface of one ton balls, sm^2		Surface of 150 ton balls, m^2		$S_{RB}^{150t} - S_{SB}^{150t}$ m^2	Balls quantity in one ton, number
Sphere	Relo	S_{SB}^{1}	S_{RB}^{1}	S_{SB}^{1t}	S_{RB}^{1t}	S_{SB}^{150t}	S_{RB}^{150t}		
10	21.49	12.56	13.69	380605	414848	5709	6223	514	30303
15	32.23	28.26	30.80	254594	277477	3819	4162	343	9009
20	43.00	50.24	54.82	191012	208425	2865	3126	261	3802
25	53.70	79.50	85.51	152996	166659	2295	2500	205	1949
30	64.43	113.04	123.21	127396	138857	1911	2083	172	1127
35	75.20	153.86	167.70	109240	119067	1639	1768	147	710
40	86.00	200.96	219.33	95456	104182	1432	1563	131	475
45	96.70	254.34	277.30	84949	92618	1274	1383	109	334
50	107.40	314.00	342.06	76302	83120	1144	1247	103	243
55	118.20	379.94	414.31	69529	75819	1043	1137	94	183
60	128.92	452.16	492.87	63754	69495	956	1042	86	141
65	139.66	530.66	578.41	58903	64203	883	963	80	111
70	150.40	615.44	670.80	54774	59701	822	896	74	89

SB, RB indicate spherical ball and Relo body ball respectively.

As a result of the specific geometry of the Relo body ball the following advantages are obtained when using this type of balls.

● The balls in the mill are arranged in several rows – fig.3. It is seen that the Relo bodies balls have a smaller height than the height of the same number spherical grinding bodies in the case of shown in fig 3 arrangement. In fig.4 are shown several different ways to arrange Relo balls in the mill. It can be seen that increasing the number of balls in the first row covering the ball in the second row, the total height of the two rows decreases. In (Tsotsorkov at al., 2010) is shown that when put 80 mm Relo body balls in industrial mill they occupy 12 % less volume of the mill than the same number of according spherical balls. This means that using Relo body balls may be put into the mill 12 % more ore/balls in comparison when using of spherical balls.

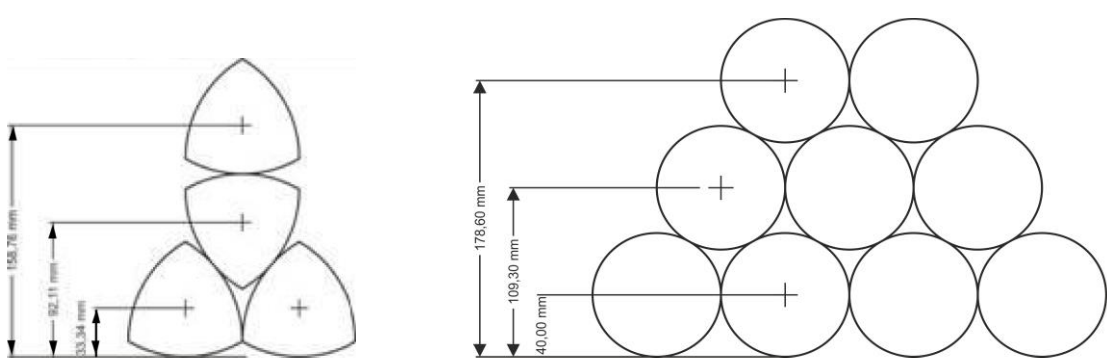


Fig.3. Distances to the centers of gravity at arrangement of spheres and Relo bodies in three layers.

Fig.4. Possible arrangement of the Relo body in two layers

● By using Hertz's theory one can determine the diameter of the circle of the contact d when two elastical-plastical spheres collide using the formulae (Zhang, Vu-Quoc, 2002)

$$d = \left(\frac{3PR*}{4E*}\right)^{1/3}, \tag{3}$$

where

$$E* = \left(\frac{1-\nu_i}{E_i} + \frac{1-\nu_j}{E_j}\right), \tag{4}$$

$$\frac{1}{R*} = \left(\frac{1}{R_i} + \frac{1}{R_j}\right) \tag{5}$$

and $\nu_i, \nu_j; E_i, E_j, R_i, R_j$ are Poison's module, elasticity modules and radii of both spheres accordingly, noted by indexes i,j.

It is seen from (3) that by increasing the radius of the colliding spheres the diameter d of the contact spot increases too. Let us look at a collision between two spheres of equal radii R1 = R2 = 40 mm and a collision between the equivalent Relo bodies with radii R3 = R4 = 86 mm. Let the two types of bodies be made of the same material and under the same conditions ($\nu_1 = \nu_2 = \nu_3 = \nu_4 = 0.3$; E_1=E_2=E_3=E_4 = 200 GPa).

By substituting in (3) the data for the two cases of collision, for the relation d_2/d_1 (d_1, d_2 are the diameters of contact spots when two spheres and two Relo body collide accordingly) we will receive $d_2/d_1 = 1,29$, i.e. the spherical surface with radius R_2 = 86 mm will have a contact spot with a diameter d_2 which is 29% bigger than the diameter d_1 of the contact spot of the sphere with radius R_1 = 40 mm.

As a result:

(i) The greater is the contact spot diameter d_1 of the spherical surface which is pressed against the mill shell the greater is the friction force between them. As a result the balls falling down will start from a great height and the impact energy of the balls will be greater.

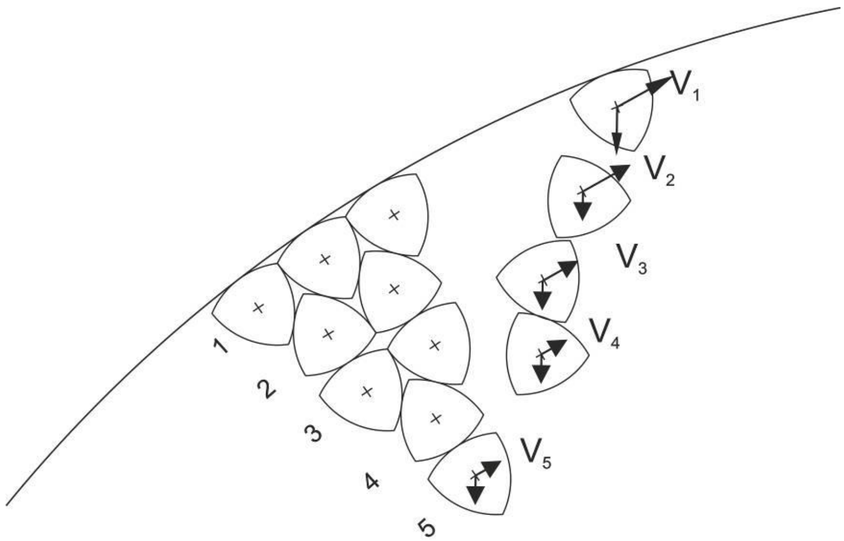


Fig.5. Positions of Relo body balls of the outer layers in the drum mill in the first moment of falling down.

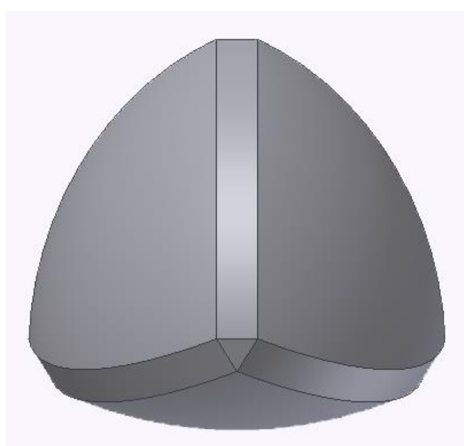


Fig.6. Relo body ball with flat bevelled edges.

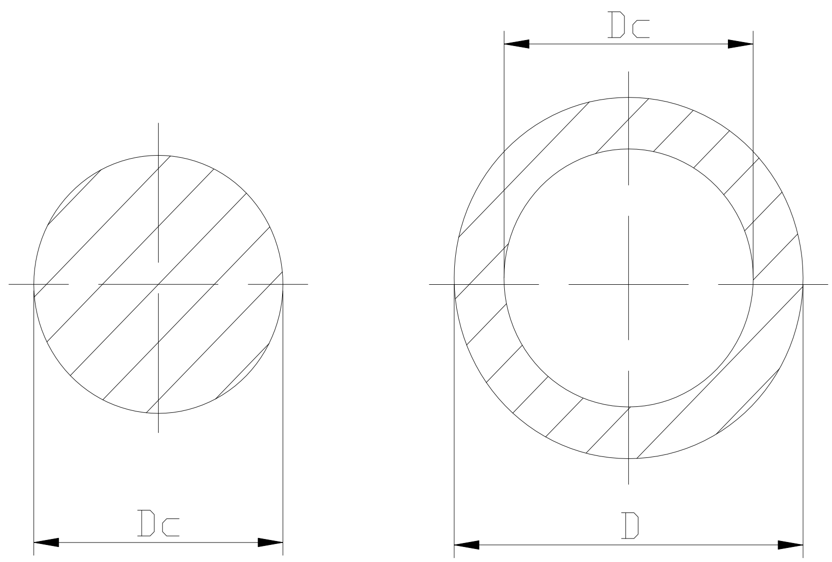
(ii) The rebound of the grinding bodies with bigger radius of the spherical surface will be less than the rebound of those with lesser radius (Aryaei at al., 2010). This means that for grinding bodies with bigger radius a greater amount of the impact energy would be used for milling of the feed in a drum mill.

In Fig.5 is shown the position of the Relo body balls from the outer layers in the first moment of falling down. It can be seen that at this moment the balls are oriented with vertex or with spherical surface down. The next move down in parabolic trajectories they retain this orientation until contact with the ore. Herewith can be explained the described in (Tsotsorkov at ai., 2010) a 100% increase of the crushing of coarse particles when using Relo body balls instead spherical balls. This effect can be even greater if used Relo body balls with flat bevelled edges – Fig.6. In this case initial shape of Relo body ball is with 12 edges which improves the efficiency of crushing of larger particles. At work in the mill these edges are gradually worn and rounded. As a result is turned out in the Relo body ball with six edges.

3. Hardness Distribution in the Ball Volume

The grinding ability and the wear resistance of the balls are determined by their hardness after quenching, which is most often defined as Rockwell hardness - HR_C. For the different used ball's materials (steel, Cr alloyed cast iron) this parameter has values $HR_C = 50 – 65$.

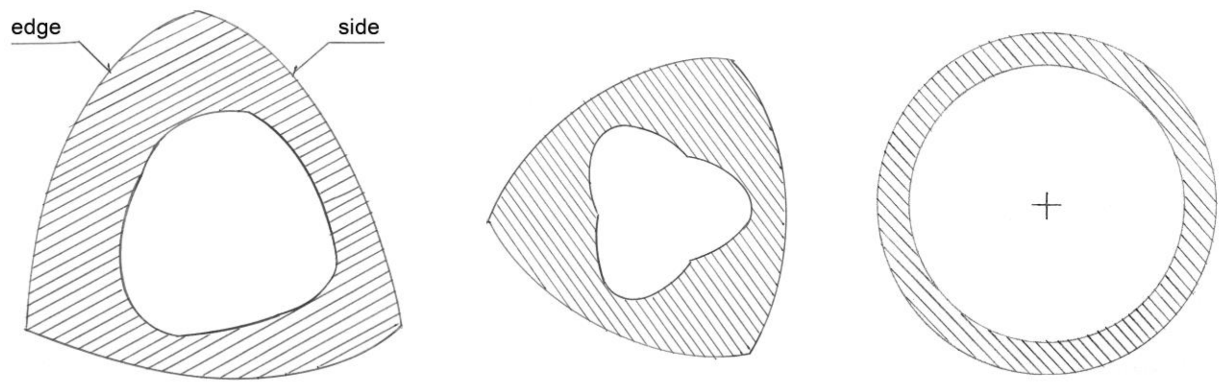
It is known (Dosset, Howard, 2006) that in the quenching of the steel balls there is a critical diameter DC at which as a result of the quenching the hardness increased to the centre of the ball-fig.2a. If the diameter of the ball D > DC , the inside of the ball can not be quenched and remains with less hardness – fig.2b. Diameter DC depends on the steel grade.



a) b)

Fig.7. Regions of increased hardness after quenching (shaded area) on steel balls.

We study the hardness of spherical and Relo body die forged balls with equal volume and made from equal steel (0.65 % C, 1.03 % Mn) . The diameter D of spherical balls is 80 mm. Both types of balls were quenched to surface hardness $HR_C =$ 60 - 62. After preparation of relevant flat samples the hardness is measured and the areas with an increase in hardness over $HR_C \geq 50$ are indentified. In Fig.8 are shown these areas (shaded area) for the both balls types (BAM Prüfbericht, 2010). Fig.8a shows the hardness area in section which passes trough a vertical edge and opposite spherical surface of Relo body ball. Fig.8b shows the hardness area in section which passes trough three horizontal edges of Relo body ball, and Fig.8c shows the hardness area in cross-section of spherical ball.



a) b) c)

Fig.8. Areas with an increase in hardness over $HR_C \geq 50$ (shaded area): a - in section which passes trough a vertical edge and opposite spherical surface of Relo body ball; b - in section which passes trough three horizontal edges of Relo body ball; c - in cross-section of spherical ball.

The calculations show that the volume with hardness $HR_C \geq 50$ in Relo body ball is 61 % greater then in spherical ball. This means that in the case of die forged steel balls the Relo body ball will work effectively (with higher wear resistance) much longer then corresponding spherical ball.

Fig.8a, b shows that the quenched area is much greater at edges and vertexes regions of the Relo body ball, then at spherical surfaces regions. This can be explained with greater cooling rate by quenching in the edges and vertexes regions, in comparison with the cooling rate in spherical surfaces regions.

4. Conclusions

As a result of the comparative analysis of the geometrical and metallurgical parameters of Relo body and spherical balls may draw the following conclusions.

Relo body ball is with 9 % - 7.5 % (2) greater surface than corresponding spherical ball. This determine the greater summary surface of the Relo body balls in the mill – Table 1, and greater comminution efficiency by attrition in comparison with the same quantity corresponding spherical balls.

Arrangement of Relo body balls in drum mill is different from that of spherical balls – Fig. 4. As a result the occupied by them volume is less then by according spherical balls (12 % less in the case of 80 mm diameter corresponding spherical balls). The released volume can be filled with additional ore or balls that will lead to increased productivity of grinding.

It is shown that the contact spot at impact between spherical surfaces of Relo body or at press of this surface to mill shall is bigger then the contact spot of the corresponding spherical ball. This affects on crushing of bigger ore particles and improves the comminution efficiency when using Relo body balls in comparison with the corresponding spherical balls.

The study of the distribution of hardness after quenching of die forged steel balls of the two types (Relo body and spherical balls) indicates that the volume with higher hardness in Relo body balls is much greater (61 % greater in the case of 80 mm spherical balls) in comparison with corresponding spherical balls – Fig.8. This means that in the case of die forged steel balls the Relo body balls will work effectively (with higher wear resistance) much longer then corresponding spherical balls.

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