The Effect of Varying Tempering Temperatures on the High Chromium Cast Iron Grinding Ball's Microstructure and Durability

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Abstract

A laboratory work has carried out to observe the effect of the tempering temperature varying on the impact toughness of the White High Chromium Cast Iron, a drop ball test was implemented to determine the ball impact resistance by dropping the ball freely on a steel anvil of 63 HRC. a life of 4210 impacts was achieved after a 1000 C^o Austeniteziation followed by 500 C^o tempering on a local made High Chromium grinding ball with 15.23 % Cr, this tempering process was tested at 550 C^o and 600 C^o where not reached more than 3200 impacts, the results of the grinding ball were proved that the applied heat treatment affected the microstructure and the hardness of the balls, the carbide volume has shown a critical rule on the impact toughness.

A carbide volume of 18.8 % was decreased till 9.223 % by the 1000 C^o Austeniteziation and 500 C^o tempering, where its hardness became 50 HRC, this is resulted in a martensitic and carbides microstructure with a little amount of retained austinite, this enhanced martensitic microstructure was shown after reducing the excessive carbide formation that gave the optimum toughness and hardness.

Key words:

Grinding balls , Drop ball , Toughness , Fracture , Hardness .

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تأثير تغيير درجة حرارة الارجاع على بنية ومتانة الكرات الطاحنة المصنوعة من الحديد الصب عالي الكروم

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ملخص البحث

أجريت دراسة مخبرية للبحث في تأثير تغيير درجة حرارة عملية المعالجة الحرارية بالإرجاع على متانة التحطم للكرات الطاحنة المصنوعة من حديد الصب الأبيض عالي الكروم، كما أجري اختبار السقوط الحر للكرات من خلالها تعريضها للسقوط من ارتفاع 6m على بلاطة فولاذية مقساة حتى 63HRC لتحديد مقاومة الكرة للصدمات المتكررة.

تم تحسين عمر الكرة الطاحنة محلية الصنع ذات محتوى كروم 15.23 % لتصل الى 4210 صدمة قبل التحطم من خلال المعالجة الحرارية برفع درجة الحرارة الى 1000 C° والوصول الى الطور الأوستينتي ثم السقاية بالزيت متبوعا بعملية ارجاع عند الدرجة 500 C° ، كما أجريت

نفس التجربة بعد تغيير درجة حرارة الارجاع تجريبياً الى $550\ C^o$ و $600\ C^o$ لكن عمر الكرة الذي تم الحصول عليه بعد هاتين الحرارتين كان أقل ، حيث لم يتم تجاوز 3200 صدمة قبل التحطم

بينت نتائج الدراسة التجريبية على الكرات الطاحنة تأثير تغيير درجة حرارة الارجاع بعد الطور الأوستينيتي على البنية المجهرية والقساوة للكرات الطاحنة المختبرة كما أظهرت نسبة الكربيدات وتوزعها في البنية دور حاسم ومهم في عمر الكرة الطاحنة على التحطم.

خفضت نسبة الكربيدات من 18.8 % الى 9.223 % من خلال عملية السقاية من الطور الأوستينيتي عند الدرجة $1000\ C^o$ متبوعا بالارجاع عند الدرجة $500\ C^o$ والتي ترافقت مع قساوة ناتجة 50 HRC في بنية مارتنسيتية مع وجود الكربيدات و القليل من الأوستنيت المتبقي ، حيث أبدت الكرة أفصل أداء على التحطم من خلال الوصول الى أفضل علاقة بين متانة التحطم و القساوة.

كلمات مفتاحية

الكرات الطاحنة، السقوط الحر، المتانة، التحطم، القساوة.

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1- Introduction

The grinding process is one of the most critical processes of the cement industry, especially for breaking down the materials till reaching the proper size, the grinding balls are working under a heavy mechanical stress like the impact and abrasive wear, these stresses lead the grinding balls to breakage and causing the grinding process failure, which affects the process operational time and the total cost.

The balls are widely used in the cement milling and many alloys of steel and cast iron are available in the industrial market for this application ,the High Chromium cast iron has shown one of the best results in the cement milling field but still need to find the suitable range of hardness and fracture toughness as the high chromium cast irons performs as a high hardness and wear resistance which comes from the very hard carbides in the microstructure but this also permits the brittleness to be minimize the durability of the balls in the mill.

Improving the fracture toughness of the grinding balls needs to apply heat treatment like Austeniteziation for reaching the destabilization of the austenite by precepting the high chromium secondary carbides, at a thermal range of 920-1060 C^o with holding for 1-6 hours, this depends on grinding ball chemical composition followed by fast quenching to the room temperature, after this heat treatment with a proper tempering in a range of 450 – 650 C^o , due to the destabilization process the austenite that become less from the carbon and chromium and can produce a harder microstructure by the martensitic transformation . the secondary carbides will distribute in the martensitic microstructure with the presence of retained austenite that is reduced in the tempering which also helping in the residual stress's reduction.[1]

Many experimental tests are used for testing the quality of the grinding balls like the Ball-on-Ball test and Ball on Block, both of them aim to study the grinding balls performance under impact conditions and following a continuous observation for the ball behavior starting from plastic deformation if happened till the fracture into two parts or more, these tests help in the ball's durability determination and the needed amount of energy to cause the fracture in the grinding ball. [2]

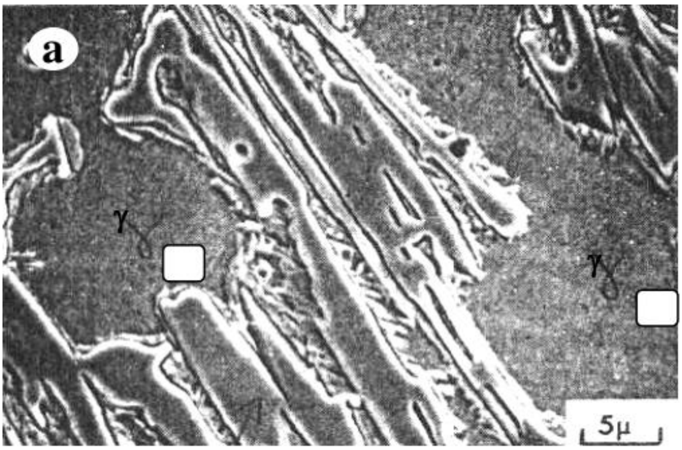

Figure 1- the as-cast microstructure, austenitic matrix with caribes

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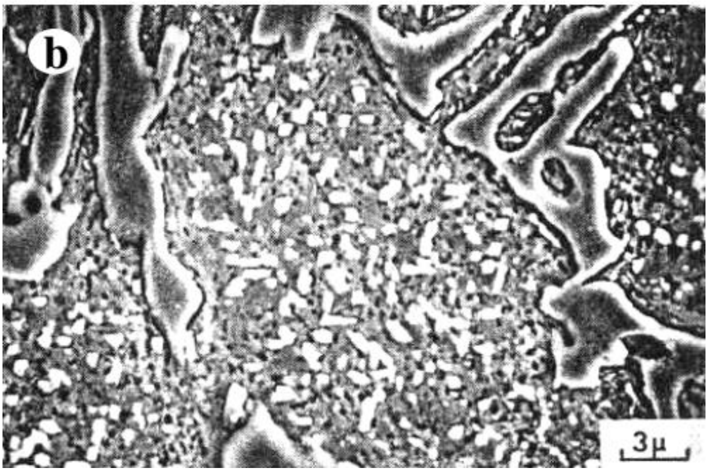


Figure 2- the martensitic microstructure with the secondary carbides in the destabilized matrix

2- Objective of the research

The research aims to improve the working durability of local grinding balls by Optimizing the heat treatment process of the High Chromium Cast Iiron grinding balls, especially the tempering temperature for enhancing the balanced relation between the fracture toughness and the hardness.

3- Material and Methodology

3-1- Material and Apparatus:

1- Local made grinding balls.
2- Grinding papers
3- Grinding machine
4- automatic Cutting machine
5- Nital solution 5%.
6- Spectrometer

7- Hardness testing machine
8- Drop ball testing machine
9- (Image J) software, image processor.

3-2- Method

The local high chromium cast iron grinding balls were experimented in a laboratory in aim of studying the tempering effect on the microstructure and its durability also, a series of preparations and experimental processes were used as follows:

3-2-1 Material description:

A high chromium cast iron grinding balls were used with a 15.23 % Cr content, D = 70 mm, local made, quantity of 12 balls.

3-2-1- Material preparation:

The balls were cut for chemical composition analysis by the automatic cutting machine.

- The samples were prepared with a grinding paper starting from size 400 till 600 – 800 – 1000 -1200 -1600 -2000 as a coarse and fine grinding.
- Samples were polished with Alumina powder
- Etching of the samples done with 2% Nital solution (aqueous nitric acid and ethanol) l.

3-2-2-Microstructure Analysis

A light microscope used to show the microstructure of the samples before and after the heat treatments of the grinding balls.

3-2-2-1- Carbide Fraction % determination

the carbides volume fraction % was determined and measured before and after the heat treatments by using the Image J software by processing the image captured from the light microscope as (B & W) black and white to clarify the selected phase percentage after removal of the other phases.

3-3- Heat Treatment process

The grinding balls were subjected to a heat treatment cycle consists of Austeniteziation and Tempering processes.

3-3-1- Austeniteziation

Raising the ball temperature for a 1000 Cº - 2 H holding – Oil quenching. (سامي، 2019)

3-3-2- Tempering

After quenching, three tempering temperatures were selected by heating the grinding balls for 500 Cº, 550 Cº and 600 Cº and keep for room temperature

. (علي، 2023)

3-4- Drop Ball Test

The ball as in commercial state and after heat treatment were tested on the drop ball testing machine to determine the impacts number that the balls can resist before fracture and to observe the ball behavior during the test like plastic deformation or spalling.

The drop ball test machine applies a free fall from 6 m height on a hardened steel anvil 63 HRC and repeating this step till ball fracture.

3-5 Hardness Test

The hardness of the balls in the commercial and heat-treated states were tested for observing the effect of the heat treatment on the ball microstructure especially the carbide's volume fraction.

3-6 Data Analysis

The results of the tests were listed in the tables and graphs plotted to show the relationship between the resulted technical properties.

4- Results and Discussion

The carbide volume fraction was the most important factor has been studied after tests and its relation to the durability of the balls and the hardness.

Three tests was done for the durability life of the grinding balls and their mean was calculated and listed in the results table NO.1 , a life of 1945 impacts was counted for the commercial local ball and this number was improved till

4210 impacts by the heat treatment of (1000 C^o - 2 H – oil / 500 -1.5 H) where the carbide volume fraction was dropped from 18.8 % till 9.23 % , this was a notable point during the experiment.

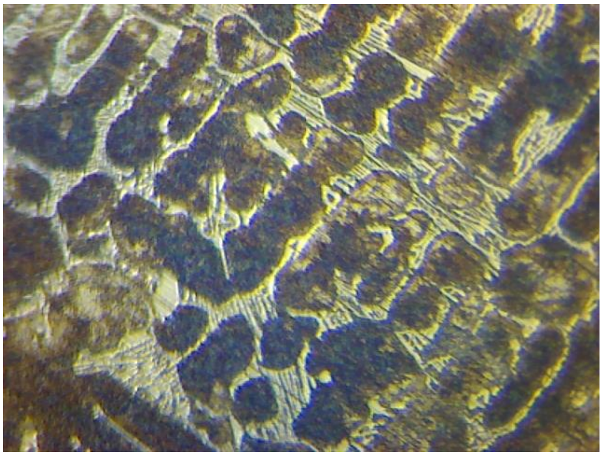


Figure 3 – Microstructure of the ball after heat treatment (X800)
(1000 C^o - 2 H – oil / 500 C^o -1.5 H)

a 3142 impacts was counted resulted after (1000 C^o - 2 H – oil / 550 -1.5 H) and the ball that was treated at (1000 C^o - 2 H – oil / 600 -1.5 H) was only resist a 1845 impacts before fracture , the carbides volume fraction was found for both 550 and 600 C^o very close in a range of 12.201 – 12.68 %

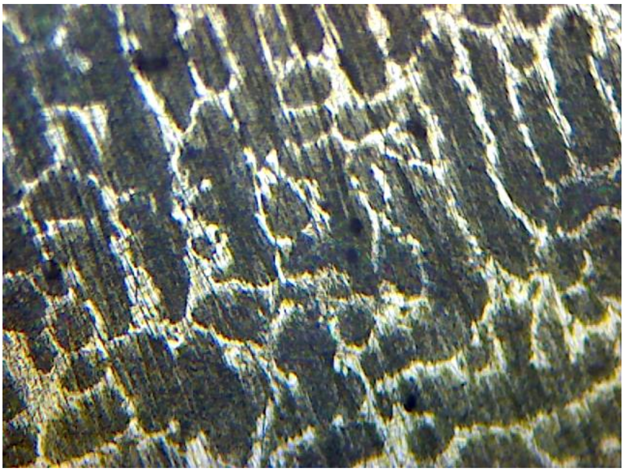


Figure 4 – Microstructure of the ball after heat treatment (X400)
(1000 Cº - 2 H – oil / 550 Cº -1.5 H)

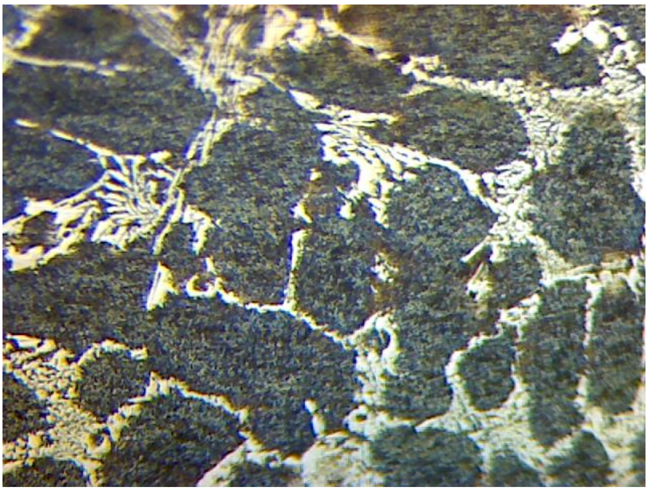


Figure 4 – Microstructure of the ball after heat treatment (X800)
(1000 Cº - 2 H – oil / 600 Cº -1.5 H)

The hardness of the balls was decreased gradually with heat treatment, started at 54.4 HRC for the commercial ball and found 50 , 49 , and 44.3

HRC respectively with heat treatment with changing the tempering temperature as 500,550, and 600 Cº.

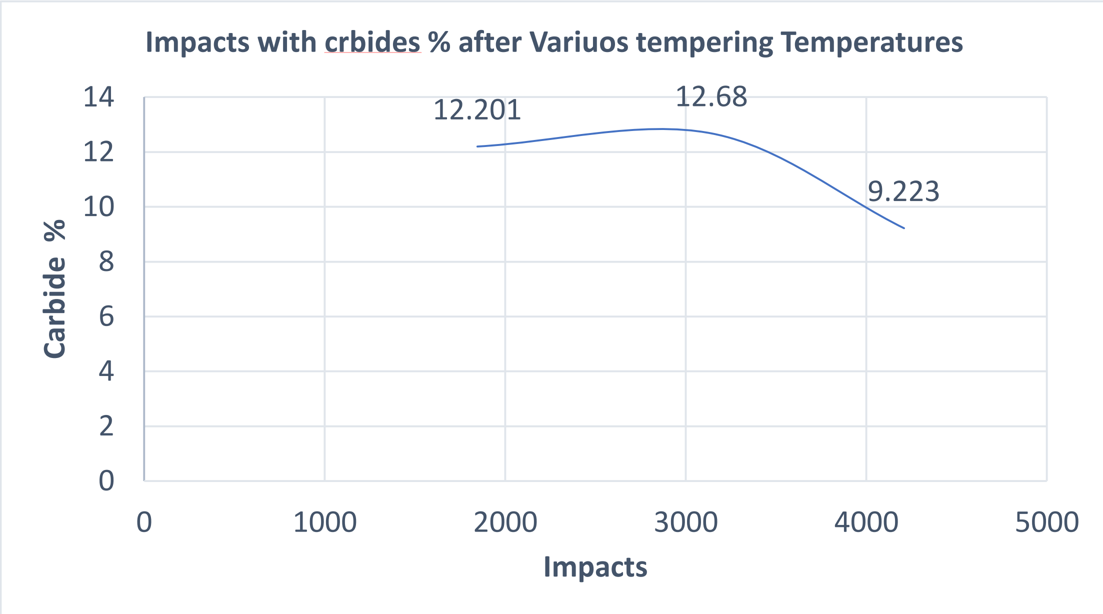
Test	Commercial	1000 /500	1000/550	1000/600
1	1855	4050	3144	1800
2	2100	4180	3380	1690
3	1940	4400	2900	2045
Mean	1965	4210	3142	1845
Carbide %	18.8	9.223	12.68	12.201
Hardness (HRC)	54.4	50	49	44.3
Failure type	Fracture	Fracture	Plastic deformation & fracture	Fracture

Table 1 – shows the tests results of the research tests

5- Conclusion and Recommendations

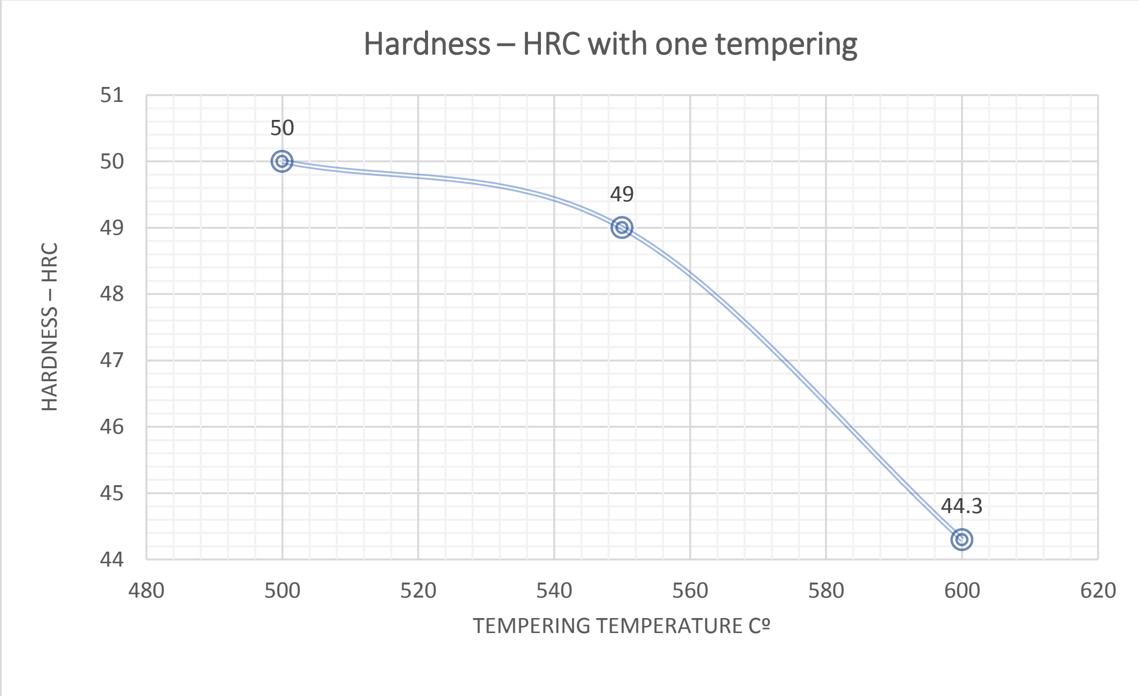
The results have shown that the applied heat treatments have a significant effect on the high chromium cast iron grinding ball's microstructure and their mechanical properties.

The most important point was to keep the optimal fracture toughness with an acceptable hardness level to maintain the wear resistance of the balls , the first heat treatment of the Austeniteziation by heating the ball till 1000 C° has caused the carbides dissolution and produced an austenitic microstructure so the carbon and the chromium will be dissolved in the austenite, and this microstructure has transformed to martensitic after oil quenching , in the tempering process especially at 500 C° , the microstructure was found as a matrix of martensite and secondary carbides and retained austenite which was controlled during the tempering by transforming most of it to martensite to eliminate its rule of reducing the hardness , this will enhance the fracture toughness , the analyses of the microscopic image of the ball was shown that the carbides has formed finely which make the matrix more able to resist the wear and repetitive impacts and can prevent the brittleness, the carbide fraction volume reduction from18.8% to 9.23 % indicated a good distribution and dispersion of the carbides in the martensitic matrix , this was with a helpful hardness value of 50 HRC for optimizing the properties .



At tempering temperature of 550 Cº and 600 Cº, the increase of the carbides fraction volume was indicated to more carbide's precipitation in the martensitic microstructure as it was ranged between 12.201 and 12.68 % respectively, this was affected the fracture toughness and decreased the number of the impacts till 3142 impacts corresponding to the 550 Cº tempering, and a 1845 impacts with the tempering of 600 Cº.

The reduced hardness value also indicates that the martensitic matrix was softened, both of excessive carbides perception and hardness decrement was a reason for earlier crack initiation ball fracture and failure.



As a conclusion, the Austeniteziation at a 1000 Cº followed by a tempering at 500 Cº is the optimal treatment for maintain the optimized properties of the local grinding balls tested, a better fracture toughness and durability and a good hardness level was resulted in double life of the grinding ball.

- **Recommendation**
- The optimal heat treatment of 1000 Cº - 2 H – oil / 500 Cº -1.5 H should be adopted for improving the local grinding balls of this composition.
- Testing the effect of repeating the tempering process for two or three times.
- Testing more holding time for the tempering process that may be affect the carbides perception.

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