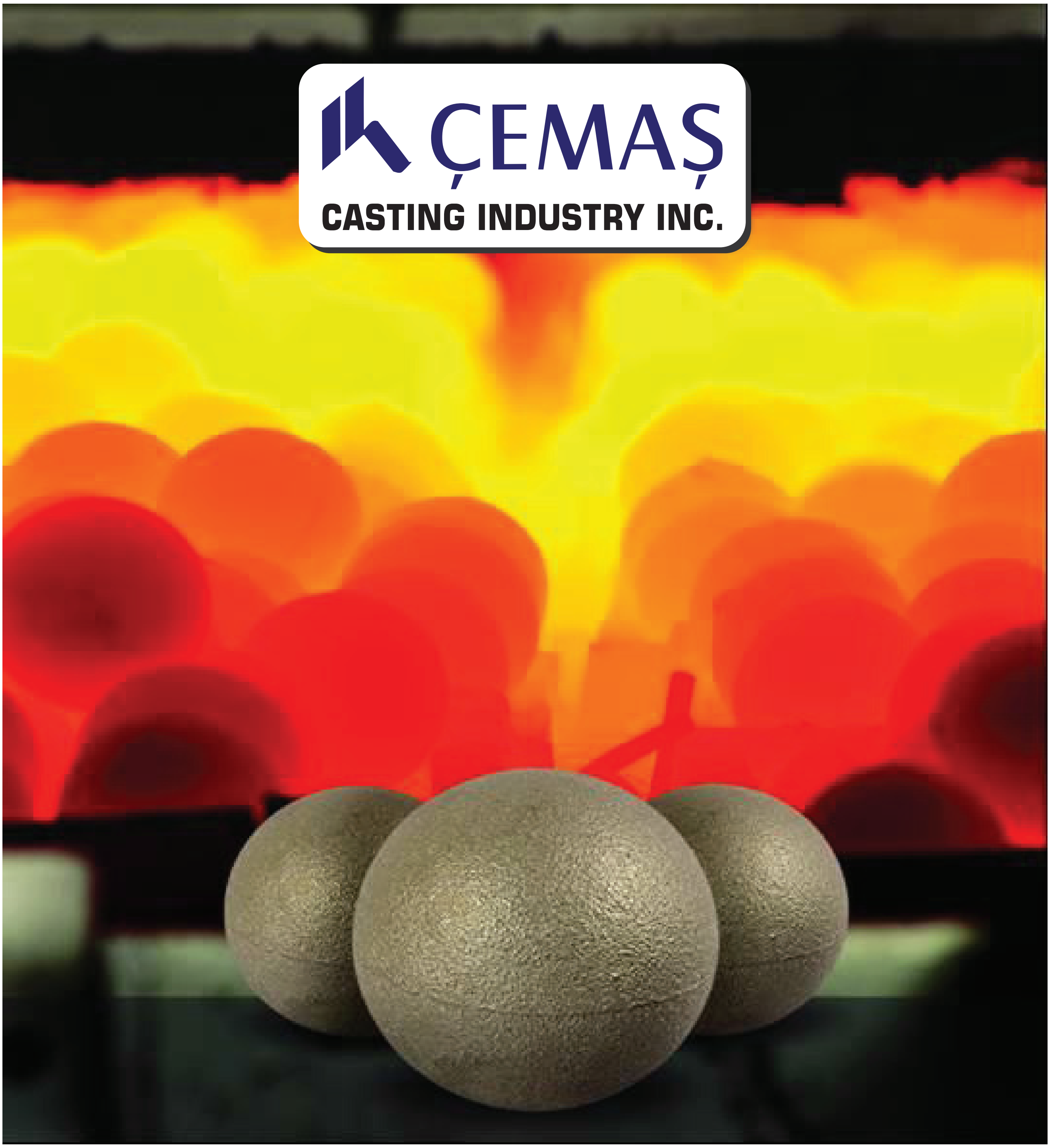


THE GRINDING BALL MASTER

Rugged Alloy | Super Crom | Utter Crom | Supreme Crom | ECO Crom

ÇEMAŞ

is a subsidiary of

ışıklar holding a.ş.

ÇEMAŞ
DÖKÜM SANAYİ A.Ş.

ışıklar
enerji ve yapı holding

ışıklar
paper sack

40.yıl
ışıklar
ambalaj

42. Yıl
ışıklar
YAPI ÜRÜNLERİ

ÇİMTEK

ÖZIŞIK

NİĞBAŞ
GÜVENLİ BİR GELECEK İÇİN

BND ELEKTRİK

METEMTEKS

HMF

SİF 50 yıl

GENERAL INFORMATION

In 1976, ÇEMAŞ developed and produced the first cast chromium balls in Turkey, in its foundry located in Kırşehir / Turkey.

ÇEMAŞ' grinding media production capacity is more than 25,000 tons/year. ÇEMAŞ produces grinding media in specialized production units for major global markets.

ÇEMAŞ continues to develop solutions to decrease wear for crushing, grinding and pyro-processing applications.

Our philosophy is to continue to be a preferred supplier by offering quality products as well as resources to fulfill our customers' needs such as improvement of technical and economic performance.

Establishment	: 1976
Capacity	: 30,000 tpy
Covered Area	: 22,000 sqm
Total Area	: 150,000 sqm
Paid-in Capital	**: 80,000,000 USD**

- ÇEMAŞ with its strong paid-in capital (quoted on BIST, Istanbul Stock Exchange), is about to start new investments for brand new moulding lines.

- The investment budget is planned to be **12M €.** After the realisation of new investments, ÇEMAŞ shall have approximately **50.000 tons/year casting capacity.**

ÇEMAŞ A.Ş. , EXPERIENCE SINCE 1976

WHERE YOU NEED PERFORMANCE OPTIMIZATION, OUR SERVICES SET THE PACE

HIGH ADDED VALUE SERVICES AVAILABLE ON DEMAND

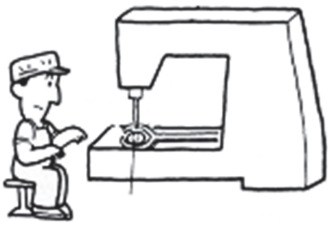
Our Engineers and Technical Specialists will analyse your needs to help implement our services which can benefit your particular case of application.

These added value services can range from logistical advice, product and/or grinding circuit performance, efficiency improvement, quality perfection studies and customer service follow-ups.

70+ Engineers and Technicians

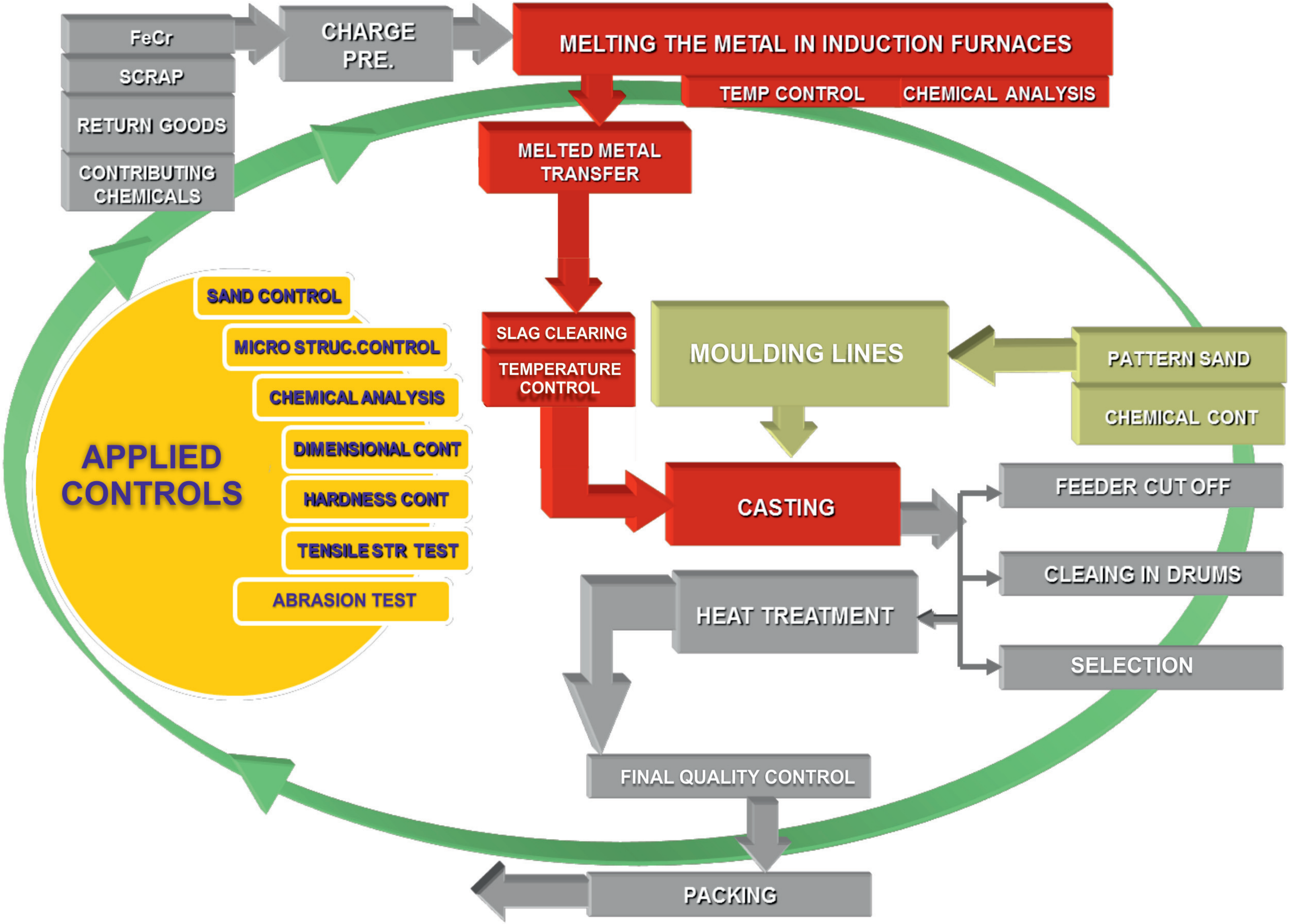
The process for Grinding Balls

- ❑ Chemical Analysis Control
- ❑ Hardness Control
- ❑ Dimensional Tolerances Control
- ❑ Feeding Breaking Control (Exc. – Dep.)
- ❑ Mismatch Control



ÇEMAŞ

PRODUCTION & CONTROL PROCESS



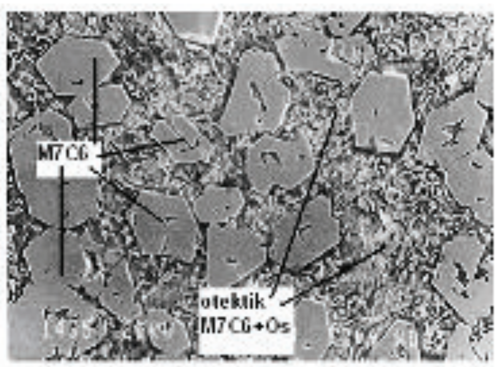
MATERIALS MANUFACTURED

GRINDING MEDIA	DIAMETER (mm)	HARDNESS	% C	% Cr	ÇEMAŞ LINE
BALL	15,17,20,25,30	60-66	2,9-3,1		
BALL	35,40,50	60-65	2,5-2,7	12-14	Rugged Alloy
BALL	60,70,80,90,100,110	59-64	2,1-2,3		
BALL	15,17,20,25,30	60-66	2,9-3,1		
BALL	35,40,50	60-65	2,5-2,7	17-19	Super Crom
BALL	60,70,80,90,100,110	59-64	2,1-2,3		
BALL	15,17,20,25,30	60-66	2,9-3,1		
BALL	35,40,50	60-65	2,5-2,7	23-26	Utter Crom
BALL	60,70,80,90,100,110	59-64	2,1-2,3		
BALL	15,17,20,25,30	60-66	2,9-3,1		
BALL	35,40,50	60-65	2,5-2,7	29-31	Supreme Crom
BALL	60,70,80,90,100,110	59-64	2,1-2,3		
BALL	15,17,20,25,30	60-67	2-3	5-6	ECO Crom
CYLPEBS (DxH)	12x12, 16x16, 19x19, 22x22, 24x24, 25x25, 28x28, 30x30, 35x35,	60-65	2,9-3,1	12-14	Rugged Alloy
CYLPEBS (DxH)	12x12, 16x16, 19x19, 22x22, 24x24, 25x25, 28x28, 30x30, 35x35,	60-67	2-3	5-6	ECO Crom

GRINDING MEDIA STRUCTURE

The balls used in the mills for grinding can be in global, cylindrical and conic shapes. The conic and cylindrical shaped balls are named CYLPEBS.

The ball consumption used per ton, the balls availability in the market, the structure of lining of the mill are important when assigning what type of ball to be chosen in the process.
In order to increase the hardness of ball , Fe3C or Cr2C3 are added to content of the ball. The hardness of ball is increased while wear rate is high levels.
The ball consumption is proportional to wear resistance. It is calculated that bigger mill diameter means higher wear rate.

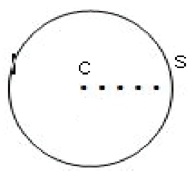


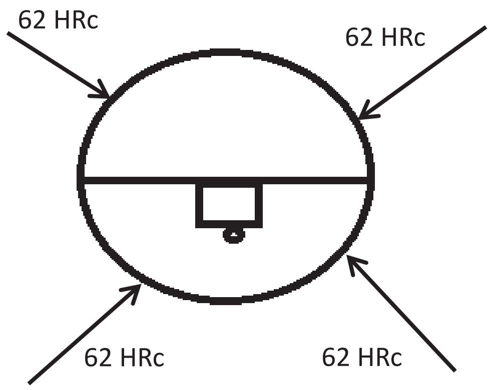
CASTING QUALITY

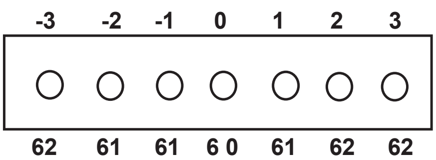
There is a martensitic structure and uniformly distributed carburets in the main body of the grinding media.
Grinding media have a uniform and spherical surface free of casting mistakes.

HARDNESS

Hardness values change due to heat treatment, changing chromium content and diameter of the grinding media. Hardness changes are shown at the above table.
To achieve a homogeneous erosion during use hardness values between the surface (S) and center (C) are maximum 2Hrc.







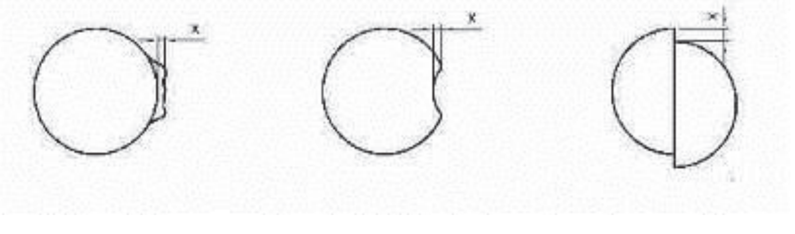
DIMENSIONAL TOLERANCE

Ball Size – Ø Diameter (mm)	Tolerance (mm)
100mm, 90mm	-2mm / +4 mm
80mm	-2 mm / +3,5 mm
70mm, 60mm, 50mm,40mm	-2 mm / +3 mm
30mm, 25mm, 20mm	-1 mm / +1,5 mm
17mm, 15mm	-1 mm / +1 mm

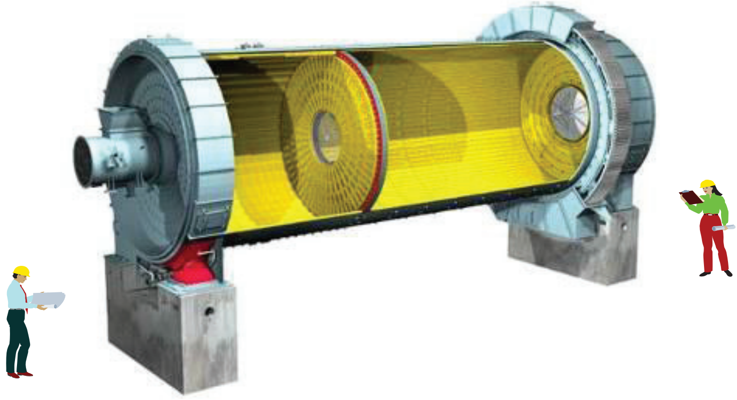
MISMATCH

Mismatch of the grinding media balls are maximum below values:

BALLS DIA (mm)	FEEDING BREAKING (X) EXCESS (mm)	FEEDING BREAKING (X) DEPTH (mm)	MAXIMUM MISMATCH (X) (mm)
< 25 mm	1,0	1,0	0,25
25,30,40 mm	1,5	1,5	0,25
50,60 mm	2,0	2,0	0,40
70,80,90 mm	2,5	2,0	0,40
100 mm	3,0	3,0	0,40



THE FACTORS WHICH HAVE AN IMPORTANT EFFECT
ON THE WEARING RATE OF GRINDING BALLS



THE FACTORS WHICH HAVE AN IMPORTANT EFFECT
ON THE WEARING RATE OF GRINDING BALLS

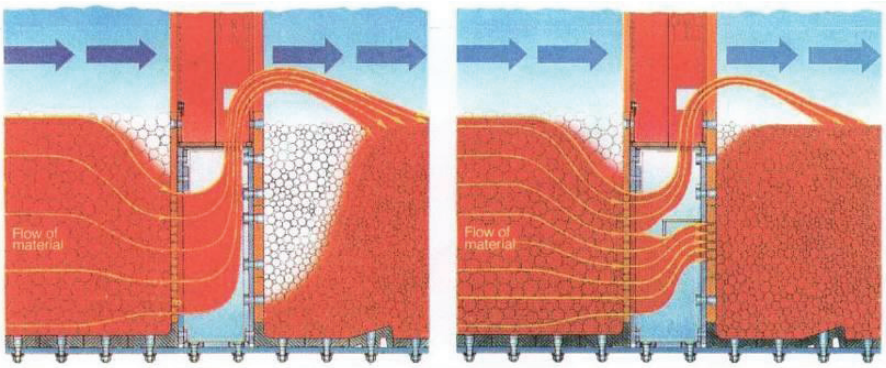
THE RIGHT PRODUCT FOR THE RIGHT APPLICATION !!!
. segmentation of grinding applications
. practical case studies
. wear performance follow-up
. knowledge management
. real-time mill monitoring (balls)

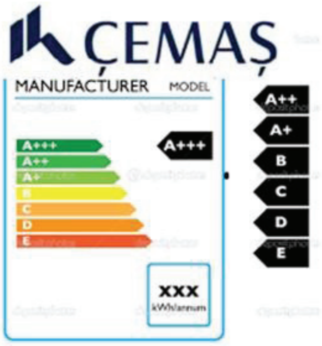
SUSTAINED IMPROVEMENT !!!
. of our standards
. of our manufacturing processes
. of our controls

THE FACTORS WHICH HAVE AN IMPORTANT EFFECT
ON THE WEARING RATE OF GRINDING BALLS

- Crashing and grinding properties of the feeding materials,
- Grinding chemicals,
- The feeding moisture value,
- Design of the inlet and the outlet diaphragms,
- Separator type and speed, (Air classifier design and operating variables),
- The grinding element size.
- The mill geometric property,
- Mill ventilation speed,
- Pre-grinding system design and operating variables,
- Lining design,
- During the grinding of the feeding material, the moisture value of which is more than %7 percent, the act of grinding decreases gradually. For the drying of the material, an additional heat must be provided for the mill.
- The identification of the effect of the moisture value on grinding and the reflection of this on the crashing and moving parameters , is quite difficult due to the changing of the heat in the mills.
- The drying and feeding of the feeding materials in dry grinding plants affect the productivity of the grinding in a positive way.

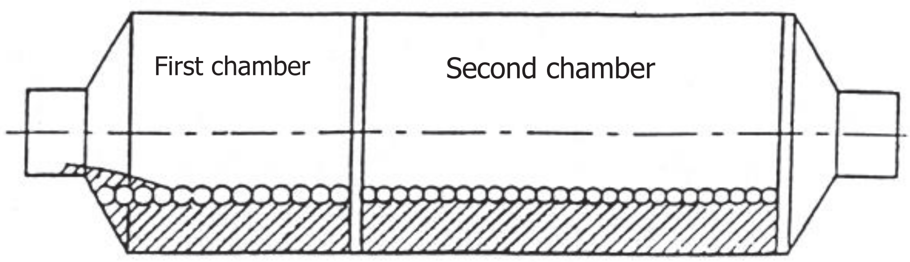
THE LINERS OF DIAPHRAGMS

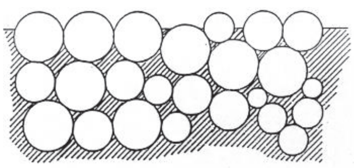


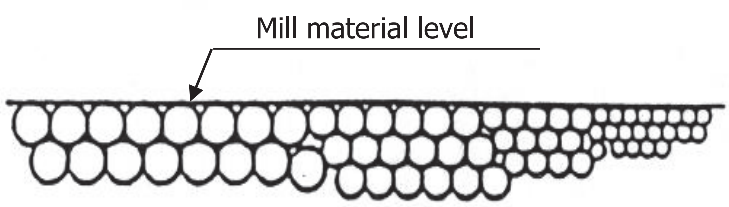


CONTROL OF THE GRINDING BALLS IN THE MILL

Correct filling material level in the mill







- The material filling in the first chamber should be seen grinding ball diameter as of 1/3,
- The material filling in the second chamber is generally round 2-10 cm higher than ball charge level,

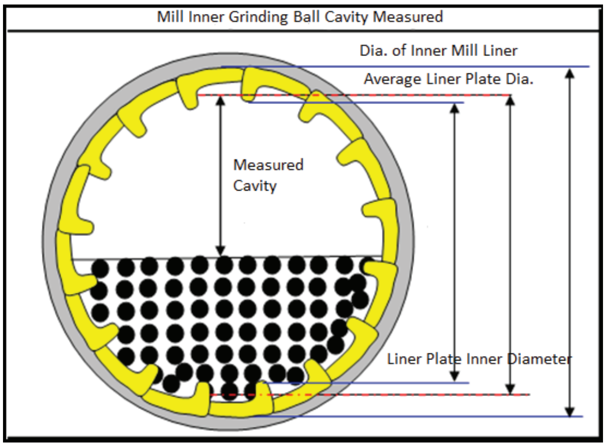
Ball Over Cement (Filling) Control

Optimum Filling Material Size:

1. Chamber

Only 1/3 of the above levels of the balls should be seen,

The middle picture is the best,
Physical Measurement,
Gap Measurement (TARGET: Determination of the amount of the actual grinding balls in the mill



Measured cavity, is the distance between average diameter of the plate and the surface of the ball.

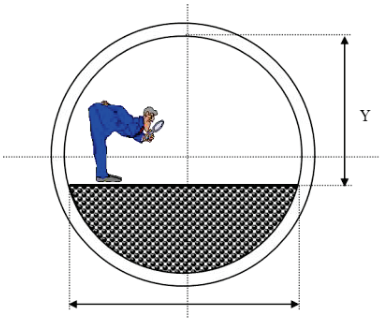
Grinding ball volume (% V)
can be detected by using of measured cavity and mill chamber dimensions.
formula could be %V : %30-34

Grinding ball weight
Can be found by multiplying contained grinding ball volume with an average value of 4.500 kg/m3.

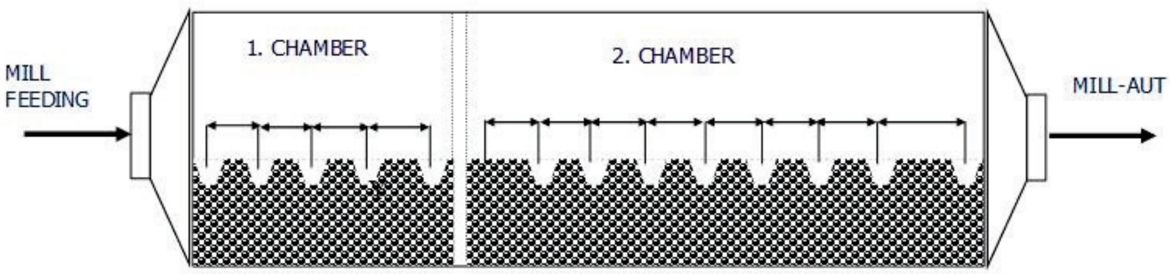
FAST & SAFE

. production capacity = 25,000 tonnes / year
. coverage : local > regional > global
. stock >< consignment
. simple order processing – easy access to order status

PERFORMANCE OPTIMIZATION

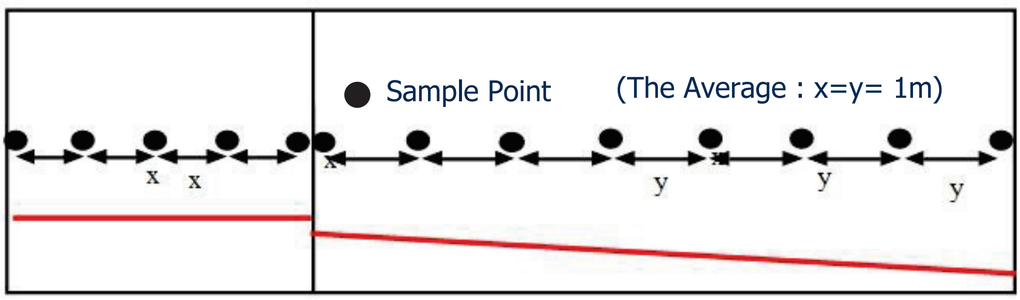


. ground product quantity
. ground product quality
. cost reduction based on :
. chemical and mineral analyses
. laboratory, pilot station and industrial testing



Physical Measurement

Mill Inlet side Ball Distribution
Purpose: the ball distribution of the mill inside and determine the classification.



1 - At each point, a certain number of balls are taken and weighed.
2 - divided in pieces, for each point, it will be determined the average weight of the ball.
3 - From the following table,
corresponding to this weight, the average diameter of the grinding ball can be found and placed in the chart.

TERMS OF GRINDING MEDIA CONDITIONS

MASTERING WEAR MECHANISMS

Whatever your application, ÇEMAS can carry out a full analysis, suggest an adapted solution and ensure its follow up. This procedure is the result of long years of study and experience practical case studies. This on-site work, carried out in close partnership with the customer, has allowed our teams, worldwide, to deepen and develop their knowledge and knowhow.

QUALITY IS NO COMPROMISE:

THIS IS YOUR SATISFACTION GUARANTEE !

Responding continuously and consistently to the particular needs of each regional market, each industry, and each customer, means that we constantly adapt our standards, our manufacturing processes, and our controls. The driving force behind this evolution being the work done on site by our Technical and Sales teams in close partnership with yourself. This global and proactive Quality Management allows us to always have our finger on the pulse.

YOUR SATISFACTION IS KEY TO OUR CONTINUOUS IMPROVEMENT.

OUR CONTINUOUS IMPROVEMENT IS KEY TO SATISFYING YOUR NEEDS.

GRINDING PROCESS;

FROM PASSION TO EXPERTISE

MAXIMIZING THE QUANTITY AND/OR QUALITY OF A MATERIAL WHILE MINIMIZING THE ENERGY REQUIRED TO GRIND IT, IS A CHALLENGE OUR ENGINEERS WILL BE TAKING UP WITH YOU.

. in your pilot grinding plants,
. on site, in partnership with you.

To do so, they will rely on the results of tests being carried out :

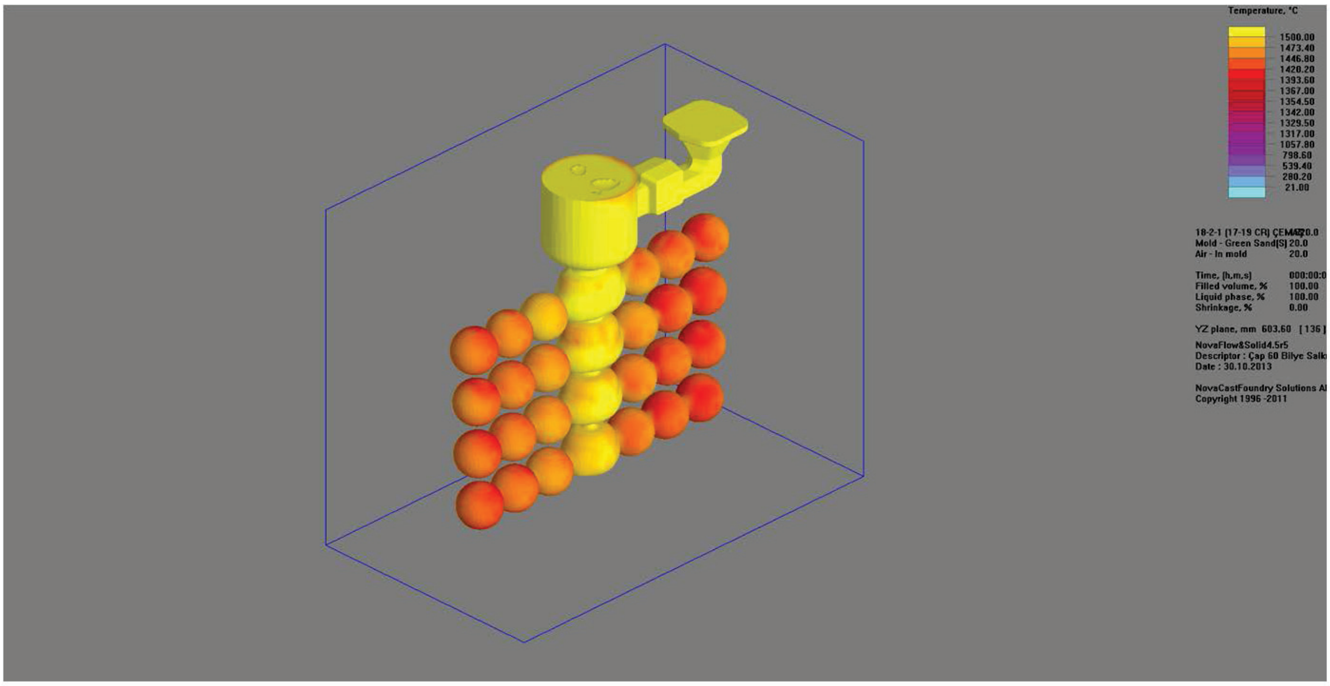
. in laboratory (hardness test, chemical or mineralogy tests…),

- During the energy-safe running time, the mill should not run in an empty position after the clinker is cut off,
- During the change of the cement type, the mill should not run in an empty position,
- During the first charging of the ball, it should start with 90 % percent ball charge in the first chamber and % 80 in the second chamber,
- After the mill starts running and reaches the normal condition, the fineness samples are taken from the first and second chamber and then the fineness curve is drawn separately. Depending on the condition, additional ball charge is made to the first and second chambers, %100 percent charging is achieved,
- The mill conditions are observed again, material analysis and ball sampling are done by making crash stop),
- As a result of inadequate charging and sorting of balls the mill capacity can be reduced and may increase power consumption.

INNOVATION FIRST

AS A PIONEER, CEMAS GOES ON INVESTING IN THE RESEARCHAND DEVELOPMENT OF GRINDING MEDIA.

- In our laboratory and our foundry, we test new techniques
- new foundry processes, and develop new products at the same time, CEMAS keeps adapting existing solutions so that these fulfill your most demanding requirements.



GUARANTEE CONDITIONS (VALID FOR STANDARD ÇEMAŞ LINE PRODUCTS)

Our breakage guarantees under normal operation conditions of ball mills and which is subjected to the ball mills not to be operated without fresh feed materials for more than 10 minutes:

In that case breakage;

a) Between % 0-2 : Within in the tolerances,

b) Between % 2-4 : The broken grinding media will be replaced free of charge,

c) Over % 4 : The mill circuit has to be completely investigated and audited by mill experts.

d) According with mill audit result that means process conditions are evaluated. Then the amount of grinding media that we would guaranteed to change will be negotiated with supplier and customer.

The above mentioned breaking Guarantee is valid only for 240 hours run time which is started under normal (optimum) conditions.

The guarantee conditions which are valid for the OPC cement (Ordinary Portland Cement) are also valid only for 1 year of run time of the mill ;

For the Closed Circuit Mills;

Between 3.000-3.400 cm²/gr Blaine values,

The wear rate is around 30 gr/ton cement (First Chamber)
The wear rate is around 15-20 gr/ton cement (Second Chamber)

Between 3.401-4.400 cm²/gr Blaine values,

The wear rate is around 43 gr/ton cement (First Chamber)
The wear rate is around 20-25 gr/ton cement (Second Chamber)

Guarantees Against Deformation or Ovalization (out-of-roundness):

Admitted ovalization for balls of 1st chamber: %15

If the ovalization for one diameter is higher than 15 % before 1 years of operation, the supplier will replace the balls as follows:

if the % of affected balls is between 0 - 5 %: no claim

if the % of affected balls is between 5 - 10 %: replacement of the involved balls

if the % of affected balls is > 10 %: replacement of the whole particular size where damage happened

Admitted ovalization for balls of 2nd Chamber: %20

If the ovalization for one diameter is higher than 20 %, before 1 years of operation, the supplier will replace the balls as follows:

if the % of affected balls is between 0 - 5 %: no claim

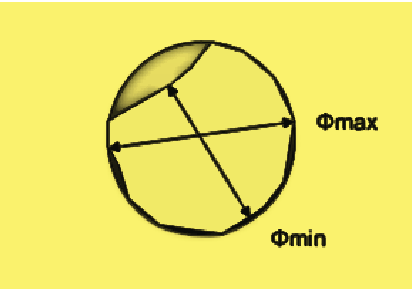
if the % of affected balls is between 5 - 10 %: replacement of the involved balls

if the % of affected balls is > 10 %: replacement of the whole particular size where damage happened.

where ovalization o is defined as:

$$o = 100 * \frac{(\Phi max - \Phi min)}{(\Phi max + \Phi min)/2} = x\,\%$$

where “x” expressed in percent is rejected above a certain fixed and decided value



OPTIMUM WORKING CONDITIONS for VALID GUARANTEE

- These all Guarantee Conditions are valid for the following optimum working conditions;
- For the first chamber; the maximum ball diameter would be 90 mm and minimum ball diameter would be 60 mm, (Larger than 90 mm balls aren’t allowed in to the mill.)
- For the second chamber; the maximum ball diameter would be 50 mm and minimum ball diameter would be 17 mm.
- Broken lines etc. aren’t allowed in to the mill,
- Chambers should be filled %22-28,
- The material filling in the first chamber should be seen grinding ball diameter as of 1/3,
- The material filling in the second chamber is generally round 2-10 cm higher than ball charge level,
- The mill should not be run more than 10 minutes without feed,
- For the first & second chamber; the total amount of ball charge will be discharged and cleaning of balls and resizing of balls for every year.
- For the other process conditions which are related with type cement and milling situations the Guarantee parameters would be recommended by supplier.

Abrasion Resistant, White Cast Iron Materials

Microstructure and properties;

Abrasion resistant cast iron materials are white, carbide-solidified cast iron materials which contain a high level of hard particles in the form of iron or chromium carbides. The carbides are held by a hard matrix. Generally, the matrix is martensitic but there are also cases of an austenitic matrix as well which only becomes more solid during the wear process associated with strain hardening.

Since they are highly resistant to wearing, white cast iron materials are particularly suitable for applications involving wear caused by minerals, for example in grinding tools, in reducing mixing and conveying equipment and systems and in pumps.

Abrasion resistant, white cast iron materials;

DIN EN 12513, which was issued in January 2001 restructured the nomenclature of the varieties of abrasion resistant, white cast iron. This replaced the previously applicable DIN 1695, in which the chemical composition was still included in the name, as in the designation of steels. The designations in the new DIN EN 12513 are based on those for cast iron, with lamellar graphite or spheroidal graphite, in accordance with the described nomenclature for the GJN. The letter N indicates white, graphite-free solidification ("no graphite"). This is followed by the hardness specification, the minimum value of which is generally the most important factor affecting the choice of material. In this connection it should be noted that the hardness of white grades of cast iron is specified according to the Vickers method.

DIN EN 12513 differentiates between 3 classes of white, abrasion resistant cast iron: Unalloyed or low-alloyed, higher- alloy nickel and chromium cast iron and high-alloy chromium cast iron. Since the materials with a high chromium content all have the same minimum hardness of 600 HV but may contain differing amounts of chromium, their designations are supplemented with "XcrY", where Y refers to the chromium content in weight in %.

Unlike other cast iron materials, the chemical composition is also included in the standard for white, abrasion resistant grades of cast iron because it determines the microstructure, response to heat treatment and, above all, the wear characteristics.

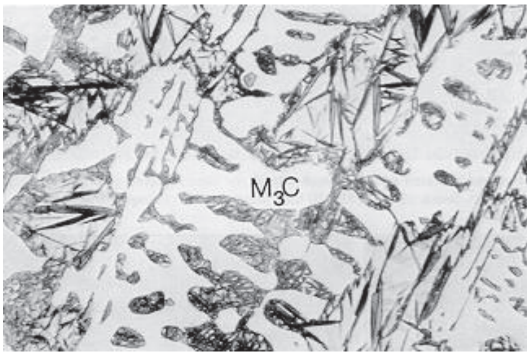
The wear characteristics of any particular type of iron material depend on a range of factors. The main factors are the basic structure, the carbon content and the type and distribution of carbides. Martensitic steels and cast iron materials, for example, are more wear resistant than austenitic grades. Pearlitic qualities, in comparison, are much less resistant to wear. In martensitic grades the starting-up conditions still have an influence on the wear characteristics, whereas the major factor for austenitic grades is the cold hardening of the austenite under the influence of the impacting wearing particles. In addition, the carbides should be evenly distributed and not too small, otherwise it is possible for a carbide to become easily dislodged from the matrix by an abrasive particle brushing along it, and then washed away.

The amount of carbide particles as hard material is dependent on the amount of carbon. The greater the carbon content, the greater the hardness if all other variables remain constant, and the lower the toughness. Hardenability can be increased with the elements nickel, copper, molybdenum and manganese. Only when these have been added is it possible to produce a hardening structure, even in larger cross-sections. However, the amount of nickel that can be added is limited because excessive amounts will lead to excessive proportions of residual austenite and even lead to the formation of graphite, thereby drastically reducing the degree of hardness.

As an alloy element, chromium offers graphite-free solidification and prevents the precipitation of graphite even during heat treatment. Like nickel, copper, molybdenum and manganese chromium also improves hardenability Furthermore, it also forms chromium mixed-carbides which are notable for much greater hardness (1200 – 1600 HV) than iron carbide (800 – 1200 HV).
Chromium mixed-carbides are also distributed more evenly in the microstructure, which is also an advantage compared to iron carbide in relation to wear. Chromium also provides improved resistance to corrosion, to such an extent that high chromium levels can achieve a performance to match that of the lower limits of stainless steels. In some grades the desired microstructure can be achieved in the as-cast condition. Others require additional heat treatment to remove unwanted microstructure portions and achieve the desired properties.

In cast parts with a high chromium content the largely martensitic basic structure is generally produced by heat treatment. Otherwise there is a risk of the presence of different pearlite, martensite, bainite and austenite elements, in dependency on wall thickness, which would make it impossible to produce the hardness in the as-cast condition with absolute reliability. Optimum service properties for these materials are not generally achieved in the as-cast condition. Nevertheless, they are certainly used for occasional applications in this condition, partly for reasons of cost but also to avoid the risk of cracking during heat treatment.

100 µm



100 µm

Microstructure of wear-resistant, white cast iron (illustrated here by GJN-HV 550)

Classification of varieties of abrasion resistant, white cast iron according to DIN EN 12513

Materials according to DIN EN 12513			Chemical composition [Weight %]								
Abbreviation EN-	Number EN-	Hard-ness HV	C Min.	SI	Mn	P	S max.	Cr max.	Ni	Mo	Cu
Unalloyed or low-alloyed cast iron											
GJN-HV350	JN2019	350	2.4 to 3.9	0.4 to 1.5	0.2 to 1						
Chromium-nickel cast iron											
GJN-HV520	JN2029	520	2.5 to 3	max .0.8	max. 0.8	0.1	0.1	1.5 to 3	3 to 5.5	-	-
GJN-HV550	JN2029	550	3 to 3.6	max. 0.8	max. 0.8	0.1	0.1	1.5 to 3	3 to 5.5	-	-
GJN-HV600	JN2049	600	2.5 to 3.5	1.5 to 2.5	0.3 to 0.8	0.08	0.08	8 to 10	4.5 to 6.5	-	-
Cast iron with high chromium content											
GJN-HV600(XCr11)	JN3019	600	>1.8 – 2.4 >2.4 – 3.2 >3.2 – 3.6	1	0.5 – 1.5	0.08	0.08	11 - 14	Max. 2.0	Max. 3.0	Max. 1.2
GJN-HV600(XCr14)	JN3029	600	>1.8 – 2.4 >2.4 – 3.2 >3.2 – 3.6	1	0.5 – 1.5	0.08	0.08	14 - 18	Max. 2.0	Max. 3.0	Max. 1.2
GJN-HV600(XCr18)	JN3039	600	>1.8 – 2.4 >2.4 – 3.2 >3.2 – 3.6	1	0.5 – 1.5	0.08	0.08	18 - 23	Max. 2.0	Max. 3.0	Max. 1.2
GJN-HV600(XCr23)	JN3049	600	>1,8 – 2,4 >2,4 – 3,2 >3,2 – 3,6	1	0,5 – 1,5	0,08	0,08	23 - 28	Max. 2,0	Max. 3,0	Max. 1,2

Optimised ball size distribution

by ÇEMAŞ Döküm Sanayi A.Ş., in cooperation with Prof. Hakan Benzer and Dr. Namık Aydoğan, Hacettepe University, Turkey

Ball size distribution is an important parameter in the application of ball mills, grinding performance can be significantly affected depending on the design of the grinding media. It is a difficult task to evaluate performance and where the problematic points are within a finish mill circuit. Simulation is the best tool to employ to improve the circuit performance if the model structures are accurate. Trial and error is an expensive and time-consuming approach. Industrial case results by Cemas indicate that a 15 -20 per cent gain can be achieved by optimising the ball size distribution, using developed model structures.

Since the 1980s tumbling mills were designed to be consistintly used to supply fine grinding for the cement industry. Due to their large and heavy design, these mills evolved into ball mills and tube mills (long tumbling) mills. After this development, the cement-making process was composed of a short mill operated in closed circuit with an air separator or long mill operated in open circuit. Subsequently, the short mills and tube mills were combined with a division head, separating the mill into two compartments. In the 1920s and 1930s, many combinations were tried for multiple compartment mills for cement grinding (Lynch and Rowland, 2005).

In tube mills, about 1-2 per cent of energy supplied is used in fracturing particles and the remaining energy ends up as heat, so internal fittings such as media charge, the mill lining system and diaphragms became important. Studies have shown that the effect of a good design versus a bad design is considerable, with savings on the specific energy consumption of 5-10 per cent being achievable. Similar increases in mill throughput were also possible (Duda, 1985).

Modern milling

Today, grinding is still an expensive process in the manufacture of cement and several variables can affect the efficiency and productivity of a dry grinding line such as operating conditions of the separators, air flow through the mill and ball sizes in the mill compartments.

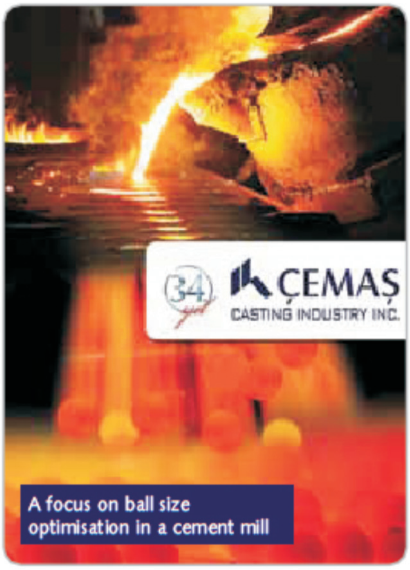
Optimising variables in the grinding lines is an important step in minimising the cost of production of cement per tonne. Ball size distribution is also a critical parameter for an efficient grinding operation. A survey covering most of cement plants in Turkey has shown that an extremely large range of ball size distribution is employed to grind the same type of material with similar grinding characteristics in different plants.

It also found that their energy consumption (kWh/t) exhibits large variations from plant to plant.

Conventional ball size selection is based on Bond's equation which advocates charging mills with the largest size of balls that can be used. The parameters affecting the choice are feed size (F80), mill type, specific gravity, work index, critical speed and mill diameter. From the largest size, the distribution of ball sizes are determined using an empirical formula. This approach has been widely accepted as an industrial standard and, therefore, its validity has not been challenged for years (Gupta and Yan, 2006).

Modelling and distribution of ball size

Mathematical modelling requires collecting extensive data around grinding circuits operating at different conditions so that the developed models can successfully predict the full-scale operation. Modelling and simulation techniques have been successfully applied to optimise wet grinding systems. These models are capable of reflecting the effect of design and operational characteristics of wet grinding ball mills on breakage rate/discharge rate (r/d) combined model parameter defined on the basis of Perfect Mixing Model (Whiten, 1976).



A focus on ball size optimisation in a cement mill

Several investigators *(Austin et al, 1975; 1984; Zhang, 1988; 1992; Benzer, 2000; 2001; Slanewski, 1985; Viswanathan, 1988; Ozer, 2006)* have studied mathematical modelling of cement mills on the basis of population balance models (PBM) for simulation and optimisation of cement grinding circuits. However, to date there is no extensive research on the analysis of effect of design and operational characteristics of dry grinding ball mills on the grinding model parameters namely breakage and discharge rate functions of particles, based on the industrial scale data.

Importance of the grinding media quality

Grinding ball production is a metallurgical operation and its quality is determined by the quality of the production process. Quality of one process has an indirect effect of the quality of another process.

The ball specifications used in the cement industry are briefly outlined in Table 1.

The ball quality parameters can be classified as the wear rate, dimensional tolerance, ovality, mismatch, gating knolls and cavity. The ball wear rate in the cement industry is 40g/t for a closed circuit application to produce a cement fineness of 3700Blaine as the abrasive content increases the ball consumption increases, ie 150-200g/t for cement with slag.

The dimensional tolerances of the grinding media should be in the maximum range of ±5 per cent. The rest of the quality figures are outlined in Table 2.

Once the quality of the balls used is assured then the optimal ball size distribution design has to be carried out for a better performance of the circuit and the balls.

Measuring ball perfomance

Before an optimal design, a complete analysis should be conducted for each milling duty. Factors such as mill dimensions, mill speed, mill power, ore type, feed top size, feed size distribution, throughput, charge volume and product size should be considered. The measurement must take account of several parameters, ie:

- energy consumption
- capacity
- product size
- liner and grinding media performance and economy.

Complete analysis involves extensive circuit sampling, sample analysis, mass balancing and data analysis. Circuit sampling is carried out under normal operating conditions, while the circuit is running at its steady-state condition when the fluctuation of the critical parameters are minimised. A typical steady-state grinding circuit condition output is shown in Figure 1.

Table 1: technical specifications of the balls used in the cement industry

Diameter (mm)	*C %*	*Cr %*	*Hardness HRC*
15,17,20,25,30	2.6-3.1	12-14	60-66
35,40,50	2.2-2.7	12-14	59-65
60,70,80,90,100,110	2.0-2.5	17-19	58-64

Table 2: ball quality parameters summary used in the cement industry

Ball size (mm)	*Ovality (%)*	*Ball size (mm)*	*Mismatch (mm)*	*Ball size (mm)*	*Gating knolls and cavity (mm)*
18-30	5-8	<25	0.25	<25	1
40-60	9-14	25, 30, 40	0.25	25, 30, 40	1.5
70-100	15-20	50, 60, 70	0.4	50, 60	2
		80, 90, 100	0.4	70, 80 ,90	2.5
				100	3

Figure 2: a typical grinding circuit and sampling points

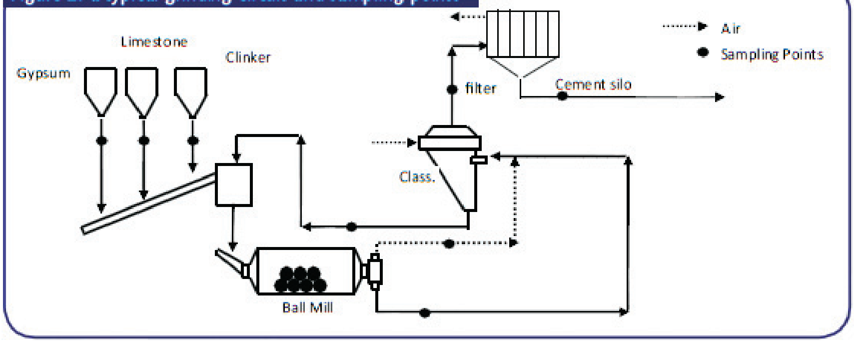
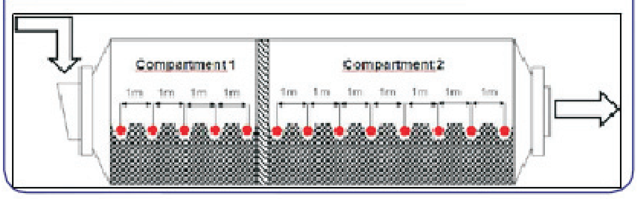


Figure 3: sampling points inside the ball mill



Operating conditions are recorded during the sampling period. To evaluate the performance of the existing circuits, for each circuit sampling surveys around the circuit are needed. A simplified flowsheet of a typical circuit with its sampling points is shown in Figure 2.

Sampling studies include all streams around the circuit, as well as inside the mill samples after a 'crush stop'. The samples inside the mill are collected along the central-axis with approximately 1m intervals. The number of sampling points inside the mill is important because it should be enough to follow the variation in size reductions. Size distribution of samples are determined down to about 2μ. Raw size distribution data then need to be mass balanced, and flow rates around the circuit are calculated on the basis of measured feed flow rates. This first attempt identifies the potential bottlenecks. A grindability test is performed on the circuit feed sample to assess performance of the actual mill. Separator performance is evaluated by examining the efficiency curve. In the Figure 3, inside the ball mill sampling points are presented.

Figure 1: a typical steady state condition output of the control system around the circuit

Milling performance depends on the ball size distribution poor vs good

Table 3: the ball size distribution before and after the change

Before			*After*		
Ball Size		*Weight required*	*Ball Size*		*Weight required*
(mm)	*(%)*	*(t)*	*(mm)*	*(%)*	*(t)*
40	22	28.16	25	29	37.12
30	30	38.4	20	21	26.88
25	26	33.28	17	50	64
20	22	28.16	Total	100	128
Total	100	128			

performance. Ball mill performance is affected by the ball size distribution. In the following paragraphs 'good' and 'bad' case studies will be presented as a part of previous work done to identify how a ball size configuration may affect the unit process.

In the first case the data collection indicated that good performance is achieved along the mill axis by obtaining the suitable ball size configuration at different points along the mill axis by classifying liner action (Slegten, 1973). Figure 4 shows the ball size distribution along the mill axis. As the material becomes finer along the mill axis, finer ball size distribution is required therefore the grinding performance is increased with a systematic size distribution (see Figure 5).

The analysis shows that systematic change in ball size distribution results a systematic size reduction along the mill axis. In this case liner configuration helps the gradation of the balls. This systematic change of the size reduction is an indication of normal operating conditions of a grinding circuit, but this does not necessarily mean that the optimum ball size distribution is being used in the system. System performance may be even better with another ball size configuration.

In the second case study, poor ball size use deteriorates the mill performance along the mill axis. Figure 6 and 7 indicate ball size distribution change and size reduction along the mill axis, respectively.

Figure 7 shows that random size distribution changes along the mill axis. This case study addresses the fact that when a good ball size distribution is not used in the system, milling conditions may be improved by another ball size distribution choice. These two practical case studies suggested that a thorough

Figure 4: ball size distribution along the second chamber

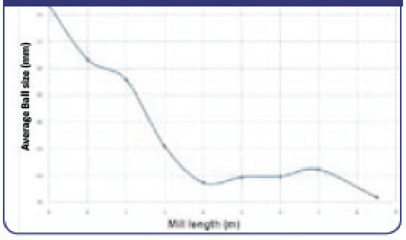
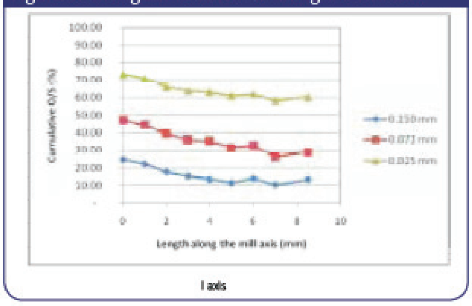


Figure 5: change in retained % along the mill axis



study is needed to establish an optimum ball size distribution for a given ore and operating conditions. As previously stated, trial and error applications are mostly expensive and time-consuming.

Determination of the suitable ball size distribution-modelling and simulation

Simulation is a valuable tool in process technology if the process models are accurate and if model parameters can be determined in a laboratory or plant. Mathematical modelling is now used widely for the design and optimisation of grinding circuits. The data obtained from the mass balancing studies were used in the model studies.

Apart from the circuit data generated by extensive sampling, determination of feed material breakage characteristics is essential for the simulation study. Laboratory scale tests are performed to generate the breakage distribution information (Genc, 2009). In ball milling studies the models developed by Hacettepe University were used (Lynch 2000, Benzer, 2001). The model parameters were determined by using the non-linear regression technique.

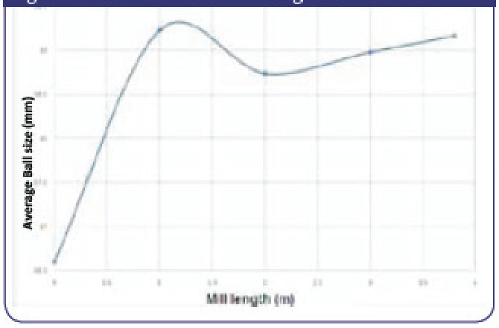
The model structure uses perfect mixing approach, providing that the mill can be modelled in segments.

$$f_i - r_i\frac{p_i}{d_i} + \sum_{j=1}^{i} a_{ij}.r_j.\frac{p_j}{d_j} - p_i = 0$$

It includes two sets of model parameters, ie the breakage function (aij) and a combined breakage/discharge rate (ri/di) function.

Ball size distribution is significantly effective on breakage rates but in some cases it may have an effect on the discharge rate as well. Performance evaluation or a sampling study is essential to calculate the breakage rate of a certain system. Additionally, material characterisation in terms of the breakage properties should be completed. In Figure 8 the breakage rate distribution of the two different ball size distribution is illustrated. These samples were taken from industrial mills. The grinding rate of Plant 1 is higher than Plant 2,

Figure 6: ball size distribuion change within the mill



therefore, it is possible to expect higher grinding performance in Plant 1.

Ball size distribution is correlated with breakage rates so for different ball size distributions, different breakage rates can be achieved. With an optimum ball size distribution, it is possible to minimise the energy consumption while maximising the milling rate. The aim is to increase the maximum impact energy and the work done by the charge.

Figure 7: change in retained % along the mill axis

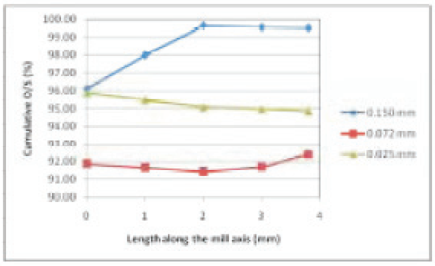
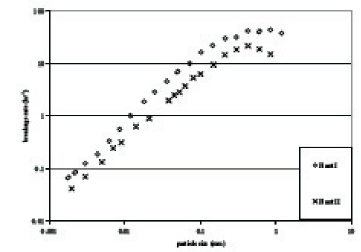


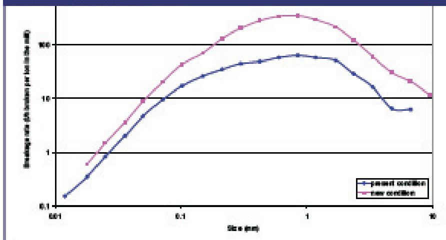
Figure 8: breakage rates of the two different ball size distribution



Circuit simulations are carried out to quantify the effects of potential disturbances on the circuit performance. For a predetermined breakage rate, it is possible to run the simulations to find out the product size distribution and the production tonnage. Different ball size distributions provide different production rates at a given product fineness. Therefore, it is possible to find out the best ball size distribution by running the simulation studies.

In the case study given below, the performance evaluation studies in a cement circuit addressed a poor performance. Therefore, an optimisation study was performed by running the simulation studies. As a result of such studies it was possible to decrease the specific energy consumption of the mill motor by changing the ball size distribution in the mill. In addition to this change it was necessary to optimise the operating parameters such as separator parameters around the circuit according to new grinding conditions.

Figure 9: the breakage rate change between the existing ball size distribution in the mill and the new ball size distribution offered



The ball size distribution recommended for the second compartment of the mill is shown in Table 3.

By changing the ball size distribution in the mill, the breakage rate in the second compartment is improved (see Figure 9). The simulation studies were conducted and the results indicated a 15 per cent specific energy consumption decrease in the process.

After implementation of the new ball size distribution the energy consumption decrease was recorded as 17 per cent. The new ball size distribution did not change the power draw of the mill, but the mill's production capacity was increased from 115tph to 150tph at the same quality figures.

The energy consumption fell from 34.48 kWh/t to 26.66 kWh/t.

Conclusion

Ball mill operation is a high cost unit operation and is affected by several parameters. Ball size distribution is an important parameter to achieve a better grinding performance. For an existing operation, measuring the performance by circuit sampling is the starting point to evaluate where the bottlenecks are located and how they are related to the performance of the circuit. Once the bottlenecks are defined, generally a better performance can be achieved by a better ball size distribution configuration. After completing the material characterisaiton, modelling and simulation is the best tool to achieve this goal. The aim is to increase the breakage rate of the mill. Ball size distribution is correlated with breakage rates so for different ball size distributions it is possible to determine the breakage rates. With the correct ball size distribution, energy consumption can be minimised while maximising the milling rate.

The aim is to increase the maximum impact energy and the work done by the charge. In this article it is shown that by using this technique it is possible to obtain reduced cost, due to less energy consumption per tonne of cement produced.

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CERTIFICATE OF ANALYSIS No: 14 – 1032-1

Cemas Dokum Sanayi AS
Ankara Asfalti 12.KM 40100
Kirsehir
Attention: **R. Stevens**

DATE: **2 June 2014**
ORDER NO : **COD**

SAMPLE DESCRIPTION: **70mm Ball (1)**

ELEMENT	Material Specification: Result
Carbon	2,44
Silicon	0,54
Manganese	0,65
Phosphorous	0,024
Sulphur	0,035
Copper	0,14
Aluminium	0,008
Chromium	11,56
Molybdenum	0,021
Nickel	0,18
Vanadium	0,044
Titanium	0,004
Niobium	0,004
Cobalt	0,008
Tungsten	0,015
Lead	0,002
Boron	0,0007
Arsenic	0,009
Tin	0,004
Magnesium	0,002
Bismuth	0,003
Antimony	0,001
Iron	Remainder

NO SPECIFICATION PROVIDED

CA/Fe Rev 3 **Spectrometric Analysis** **ELECTRONIC COPY** The results relate only to the sample tested.

Results Expressed in % **Authorised Signatory ....D. SHARP.........................**

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CERTIFICATE OF TEST No: 14-1035-1A-1

Cemas Dokum Sanayi AS
Ankara Asfalti 12. KM 40100
Kirsehir

Attention: ***R. Stevens***

DATE: **4 June 2014**

ORDER No: **COD**

Hardness Test - Grinding Balls

Cemas Dokum	*Size: 70mm*
Depth from Surface (mm)	*HRc*
5	*59*
10	*59*
15	*59*
20	*58*
25	*59*
30	*59*
35	*57*

Surface Hardness: *59HRc*

NO SPECIFICATION PROVIDED.

IP 1 Rev 0 **ELECTRONIC COPY**

Witnessed By : ....

Authorised Signatory: D.Sharp

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CERTIFICATE OF TEST No: 14 – 1032-1A

Cemas Dokum Sanayi AS ***Ankara Asfalti 12.KM 40100*** ***kIRSEHIR*** ***Attention:*** ***R. Stevens***	**DATE:** **04 June 2014** **ORDER No:** **COD**

Microscopic Examination - Grinding Balls

Size: *70mm*

Microstructure: *Primary eutectic carbides in a matrix of fine tempered martensite containing some fine secondary carbides.*
(Photograph 14-1032-1)

Defects: *Some inclusions observed but these are not deemed detrimental.*

No Specification Provided

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Cemas Dokum Sanayi AS.	
Ankara Asfalti 12.,KM 40100	**DATE:** **04 June 2014**
Kirsehir	
	ORDER No: **4501313360**
Attention: ***R. Stevens***	

Microscopic Examination - Grinding Balls

Size:	*70mm*
Microstructure:	*Primary carbides in a matrix of fine tempered martensite containing some fine secondary carbides*
Defects:	*None seen on the section examined. No retained austenite.*

No Specification Provided

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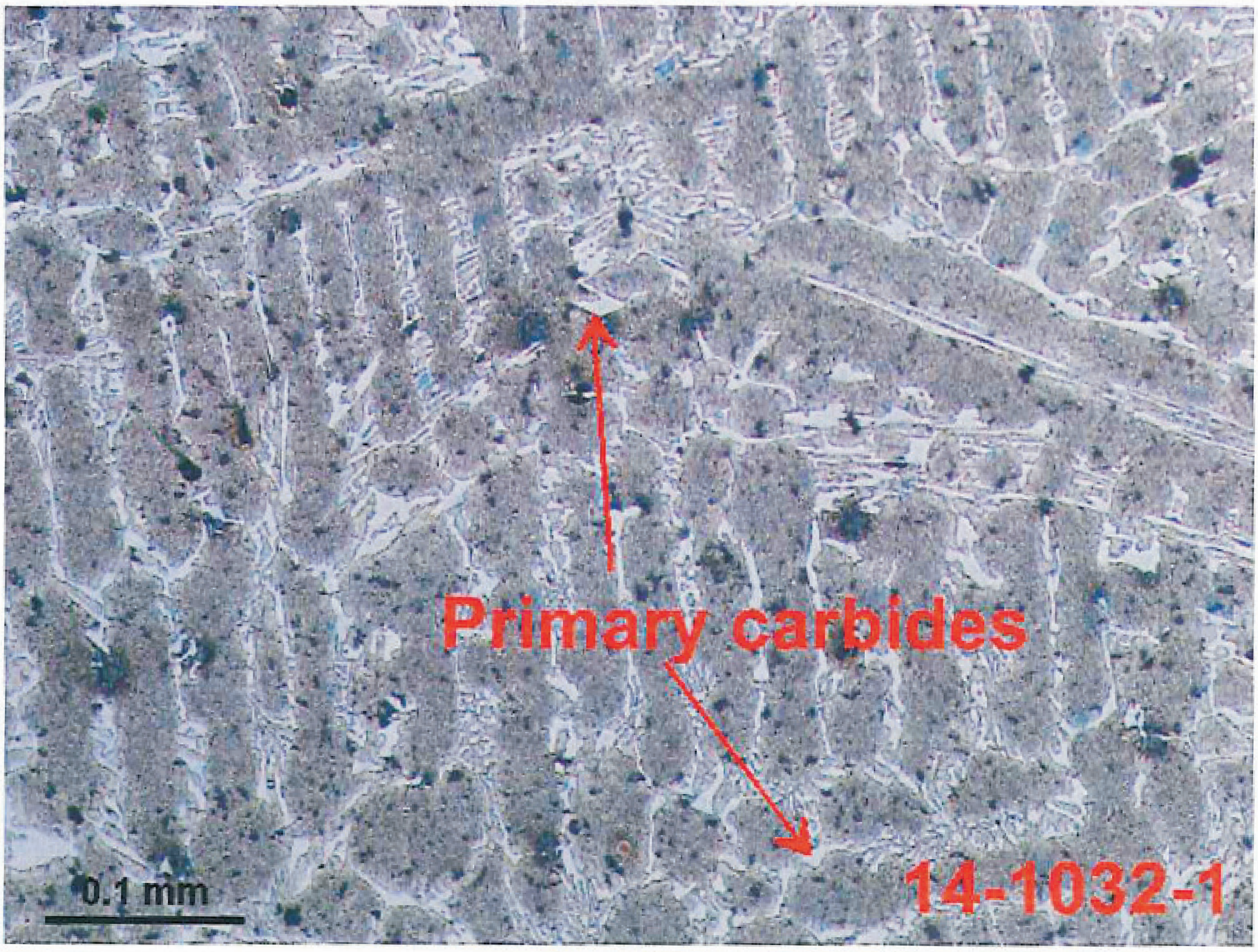
Authorised Signatory: P.HEINTZBERGER



14 – 1032-1
70mm Ball - Microstructure
Mag X 200

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CERTIFICATE OF ANALYSIS No: 14 – 1032-4

Cemas Dokum Sanayi AS **Ankara Asfalti 12.KM 40100** **Kirsehir** **Attention: R. Stevens**	**DATE: 2 June 2014** **ORDER NO : COD**

SAMPLE DESCRIPTION: **40mm Ball (4)**

ELEMENT	**Material Specification:** **Result**
Carbon	2,67
Silicon	0,84
Manganese	0,74
Phosphorous	0,025
Sulphur	0,042
Copper	0,21
Aluminium	0,005
Chromium	12,83
Molybdenum	0,027
Nickel	0,25
Vanadium	0,066
Titanium	0,006
Niobium	0,012
Cobalt	0,007
Tungsten	0,018
Lead	0,001
Boron	0,0009
Arsenic	0,009
Tin	0,006
Magnesium	0,002
Bismuth	0,002
Antimony	0,001
Iron	Remainder
NO SPECIFICATION PROVIDED	

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Results Expressed in % **Authorised Signatory ....D. SHARP.........................**

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Hardness Test - Grinding Balls

Cemas Dokum	*Size:* *40mm*
Depth from Surface (mm)	*HRc*
5	*62*
10	*62*
15	*60*
20	*56*
Surface Hardness: *62HRc*	
NO SPECIFICATION PROVIDED.	

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Authorised Signatory: D.Sharp

DISCLAIMER: Whilst making every effort to ensure the accuracy of our results, they are without guarantee or warranty.
PLEASE NOTE: Samples will be discarded after 30 days
MEMBERS: P.Heintzberger BSc (Hons) M. Gertzen, D. Sharp

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Cemas Dokum Sanayi AS ***Ankara Asfalti 12.KM 40100*** ***kIRSEHIR*** ***Attention:*** ***R. Stevens***	**DATE:** **04 June 2014** **ORDER No:** **COD**

Microscopic Examination - Grinding Balls

Size: *40mm*

Microstructure: *Primary eutectic carbides in a matrix of fine tempered martensite containing fine secondary carbides.*
(Photograph 14-1032-4)

Defects: *No defects observed on the section examined.*

No Specification Provided

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e-mail: implabs@lantic.net

CERTIFICATE OF TEST No: 14 – 1032-4A

Cemas Dokum Sanayi AS ***Ankara Asfalti 12.KM 40100*** ***kIRSEHIR*** ***Attention:*** ***R. Stevens***	**DATE:** **04 June 2014** **ORDER No:** **COD**

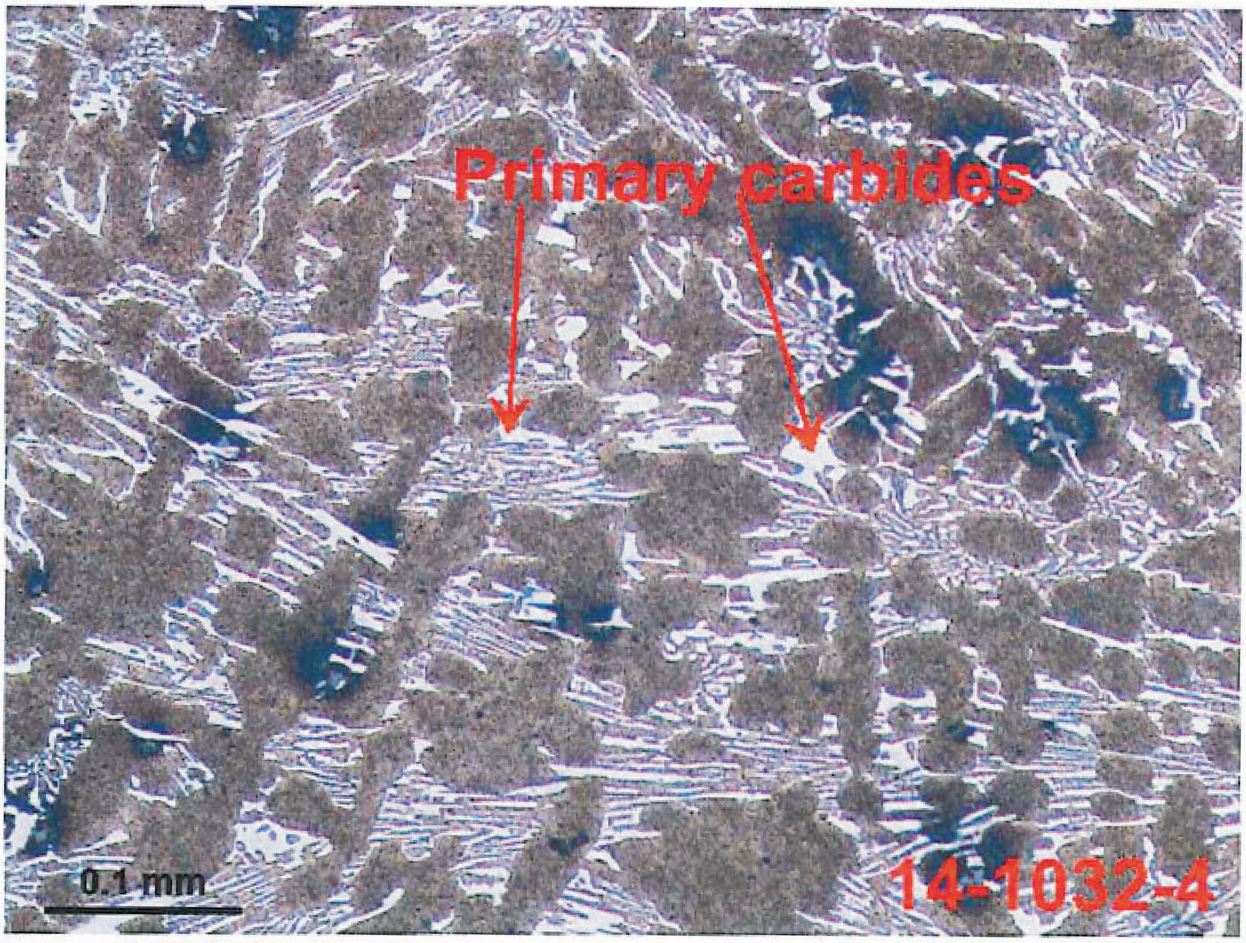
Microscopic Examination - Grinding Balls

Size:	*40mm*
Microstructure:	*Primary eutectic carbides in a matrix of fine tempered martensite containing fine secondary carbides.* *(Photograph 14-1032-4)*
Defects:	*No defects observed on the section examined. No retained austenite.*

No Specification Provided

IP 2 Rev 1 **ELECTRONIC COPY** The results relate only to the items tested.

Witnessed By : ……………………………………….. **Authorised Signatory: P.HEINTZBERGER**



14 – 1032-4
40mm Ball - Microstructure
Mag X 200

COMMUNICATION

Address : Ankara Asfalti 12. km 40100, Kirsehir
Tel : +90-386 234 80 80
Fax : +90-386 234 83 49
E-mail : cs@cemas.com.tr

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