Introduction to Crushing

Bill Malone

QUARRY ACADEMY

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Material Characteristics

Rocks and ores

- **A rock consists of minerals and chemical compounds. There are at least 2500 different minerals, each with its own composition and internal structure. A rock often consists of at least two minerals. This explains why one kind of rock can exhibit such differing characteristics. Even so, just a few minerals make up the major constituents of the most common types of rock. Most of these minerals are silicates.**
- **An ore is simply a rock with a metal content that is high enough to make exploitation economically viable.**

Volcanic rocks	Hypabyssal rocks	Plutonic rocks
Cooled in deep intrusions. Slow cooling = coarse crystals.	Cooled in dykes and sills during magma flow towards the surface of the earth. Fast cooling = fine crystals.	Cooled on the surface of the earth's crest. Very fast cooling = very fine crystals.
Examples Granite Diorite Gabbro	*Examples* Diabase Porphyry Porphyrite	*Examples* Basalt Andesite Obsidian

Material Characteristics

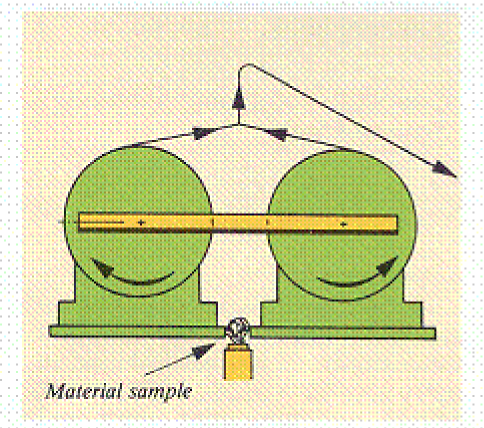
Rocks are usually classified according to the way in which they are formed:

- **Igneous rocks, also called magmatic and eruptive rocks, have been formed from melted minerals, magma. They are further classified depending on where they have cooled off and crystallized:**
- **Sedimentary rocks can be composed by weathered rocks or by disintegrated animal shells, bones etc. Nearly all are made of materials that have been moved from a place of origin to a new place of deposition. Running water, wind, waves, currents, ice and gravity move material on the surface of the earth. After the particles have sedimented, they have slowly been consolidated into a rock. The transport often results in a gradation according to grain size and/or type of mineral. Fossils are often included. Sedimentary rocks cover about 75% of the earth's crest. Examples are sandstone, limestone, greywacke and shale.**
- **Metamorphic rocks are transformed igneous or sedimentary rocks. The original rock has been altered physically and sometimes chemically by the application of intense heat or high pressure. Examples of metamorphic rocks are gneiss (origin: granite), quartzite (origin: quartz sandstone), amphibolite (origin: diabase/basalt) and marble (origin: limestone).**
- **From a chemical viewpoint rocks are sometimes grouped as acid or basic, depending on the silica content (SiO_2). The acid rocks have higher silica contents than the basic rocks and are also more resistant against weathering. Examples of acid rocks are gneiss and granite. Basic rocks are basalt and diabase.**

Material Characteristics

Work Index or Crushability of rocks

- **Not even two samples of a single type of rock necessarily exhibit identical characteristics. They may come from different parts of a quarry or from different depths in the same bore hole. Names like limestone, granite or diabase describe the type of rock, but give only a rough indication of the characteristics. The term "gravel" gives almost no information and does not even describe the type of rock.**
- **One way of determining crushability is to measure the energy required to crush a material. Fred C Bond, Allis-Chalmers, developed about 1950 a method to calculate the energy using a parameter called Work Index (WI). The Work Index of a material is important for the selection of a crusher: type, size, eccentric throw, setting and motor size. In practice, the energy measurement according to Bond's method is carried out with an impact-testing machine. The impact strength of a rock is an important measure of its toughness and crushability.**



Material Characteristics

- **Ten stones, between 55 and 70 mm in size, are each subjected to simultaneous impact from two pivoted hammers, one on each side. A small drop height (rotary angle of the wheels) is used at first, but increased successively until the test stone breaks. The energy required - in Nm - is divided by the thickness of the stone - in m - to give an impact strength expressed in N. With the help of an empirical formula, the material's Impact Work Index (WI) can be deduced from its impact strength and density.**
- **Wi results from different laboratories are usually not comparable due to incomplete standardisation of the test method.**

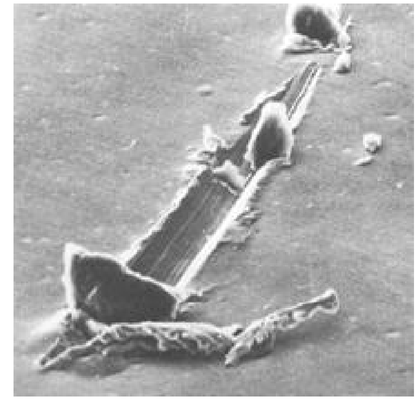
Material	Density (kg/m³)	Impact Strength (N)	Work Index
Dolomite	2.75	700	12
Limestone	2.69	720	13
Magnetite (Iron Ore)	4.6	750	8
Gneiss	2.72	910	16
Granite	2.68	940	17
Quartzite	2.65	970	18
Hematite (Iron Ore)	4.42	1040	11
Diabase	2.84	1060	18
Basalt	2.84	1160	20

Typical test results from the Sandvik Rock Processing Test and Research Center, Sandvik Rock Processing:

Impact Work Index is calculated as $WI = 0.00485 \frac{IS}{SD}$

where IS is the average impact strength of the rock samples tested and SD is the solid density.

Material Characteristics



Abrasion Index of rocks

- **Most rocks contain mineral grains that are harder than steel. They are then able to scratch the surface, remove steel and thus create wear.**

- **The abrasive characteristics for a certain rock is measured by the determination of its Abrasion Index, AI.**

The machine shown on the right is used for the test. The Abrasion Index is determined on basis of the loss of weight of a small steel paddle, which rotates for one hour in a drum with 400 g of the material being tested. The size of the material is 12.5-19 mm. Due to disintegration in the drum, it is replaced by to new material every 15 minutes.

Material Characteristics

Abrasion Index of rocks

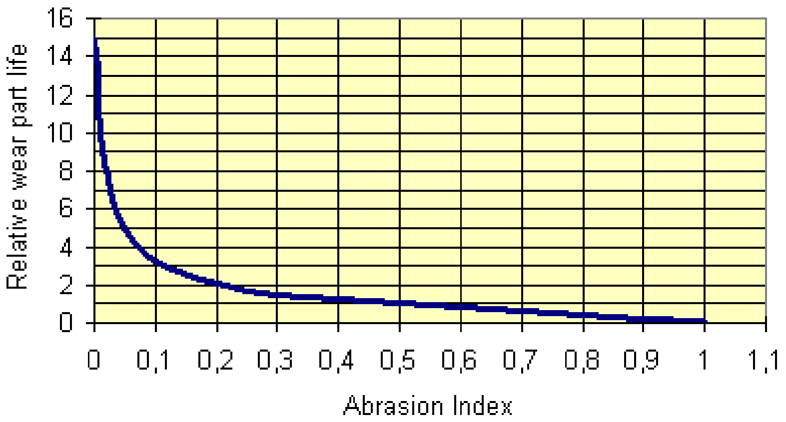
The weight loss in gram makes the Abrasion Index. Both test paddles above have operated during one hour but in different rocks. The test result enable us predict wear rates and guide us to select the most suitable machine or wearing part alloy.

The abrasive characteristics for a certain rock is measured by the determination of its Abrasion Index, AI.

The diagram to the right, gives an overview of how the Abrasion Index affects the wear part life. The AI of 0.5 corresponds to the relative life of 1, say 100 000 tons of production in a certain crushing application. If AI is 0.2 instead, the relative life is increased to 2. The same wear part will then last for 200 000 tons.

Typical test results from the Sandvik Rock Processing Test and Research Center, Svedala:

Material	**Abrasion Index**
Limestone	0.001
Dolomite	0.02
Basalt	0.25
Diabase	0.28
Granite	0.46
Gneiss	0.48
Quartzite	0.79



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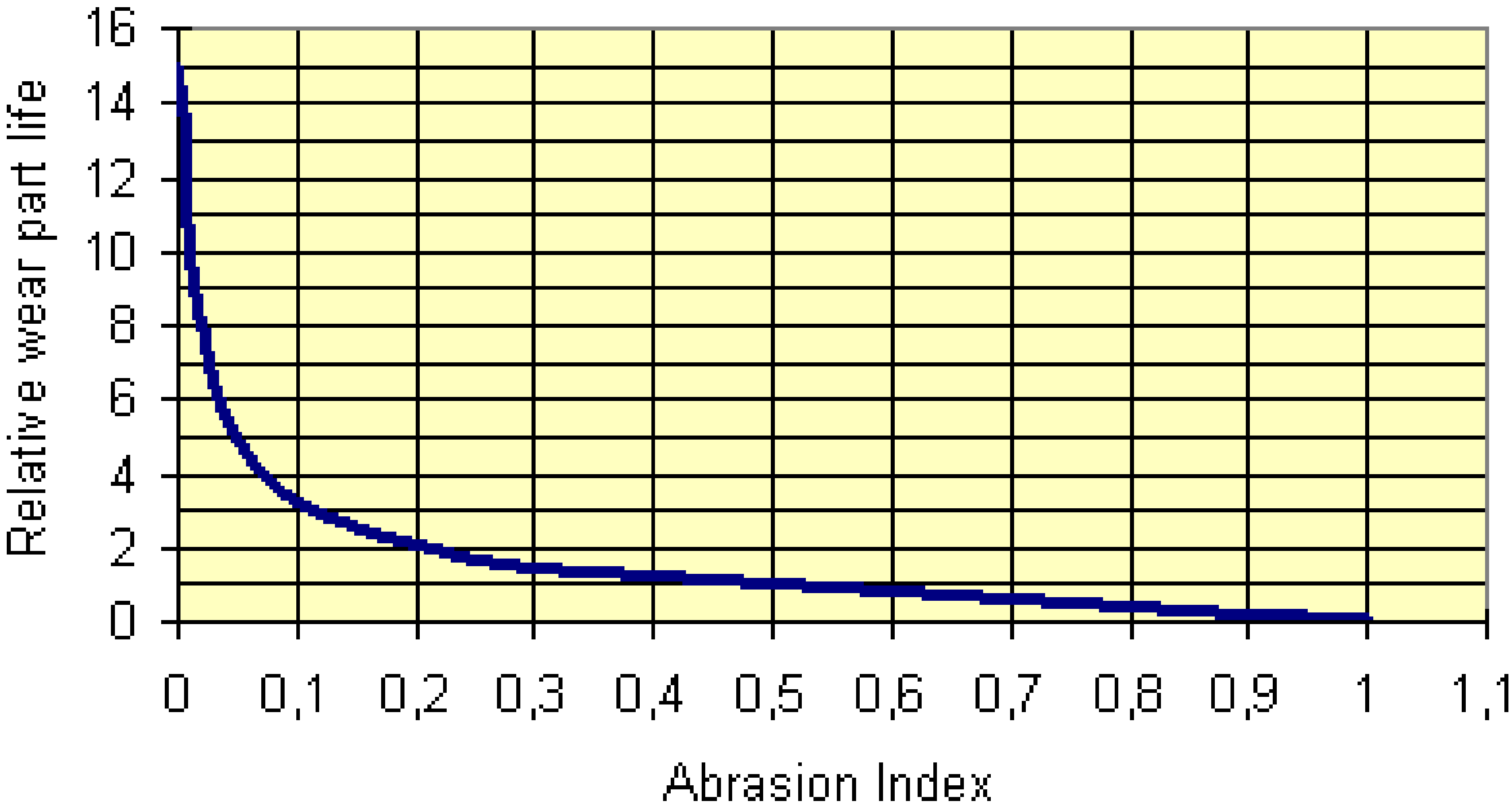

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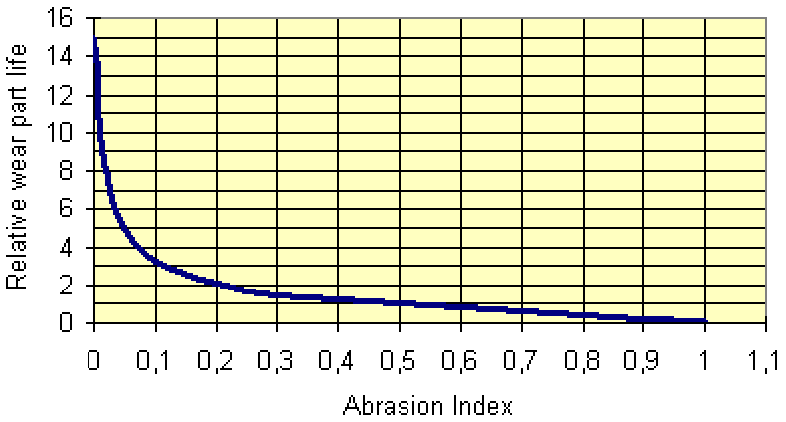

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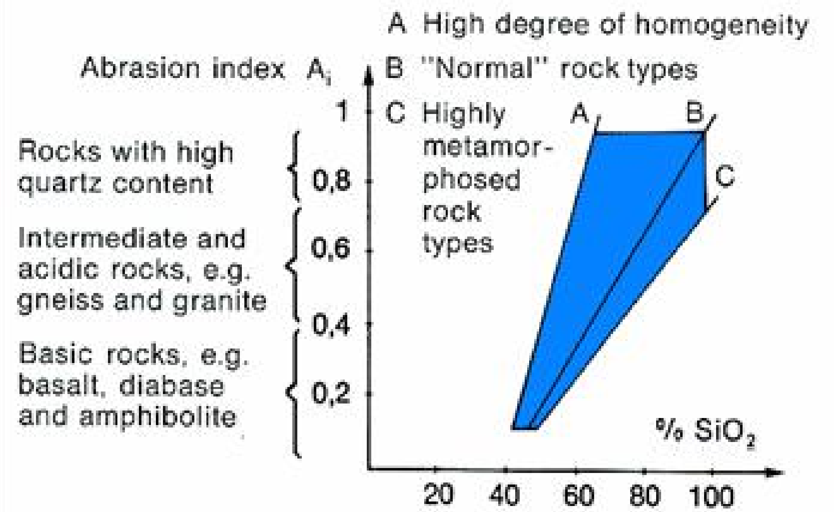
Material Characteristics

Abrasion Index of rocks

- **AI results from different laboratories are usually not comparable due to different reference materials in the paddles.**
- **Do keep in mind that hardness of a rock and Abrasion Index are not connected. A hard material that is difficult to crush is not necessarily very abrasive - the rock does not have to contain hard grains that cause abrasion. As mentioned above, it is hard grains in the rock that cause abrasion. For example a soft, easily crushed quartzite is always very abrasive due to the hard quartz grains. However, a hard rock may give a long life of manganese wear parts as it enables work hardening of this material.**
- **Quartz is the most common mineral next to feldspar in the earth's crest. It is the crystalline form of silicon dioxide, SiO2, also named silica. The total silica content of a rock is decisive for its abrasive properties: The higher the silica content, the higher the wear on the crusher liners. From experience we know that there is a approximate relationship between the Abrasion Index AI and the silica content of the material.**



Relationship between A_i and SiO_2 content for eruptive and metamorphic rocks

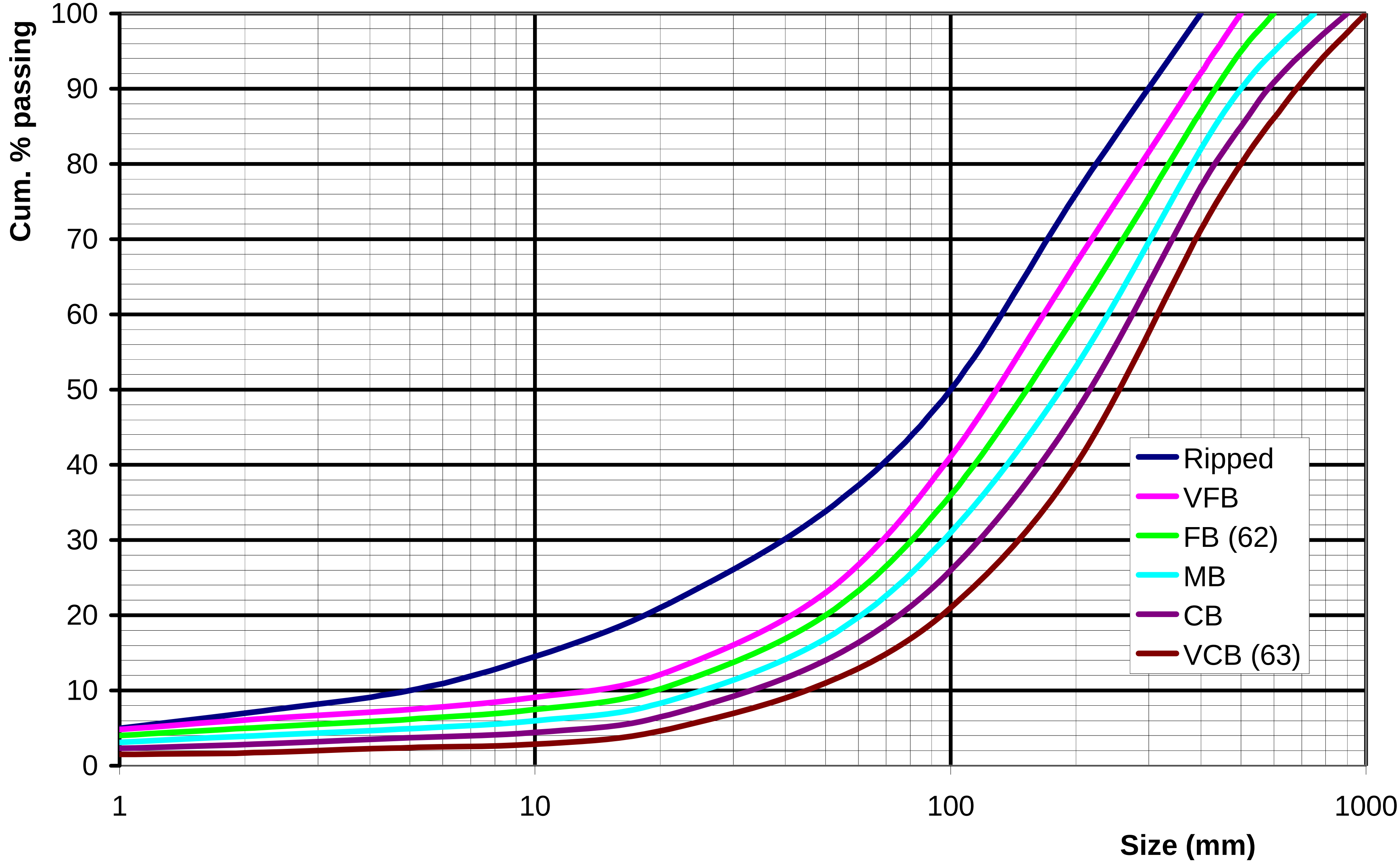
Material Characteristics

TEST DATA STATISTICS

2003-12-16

Material	No of Tests	Density			Work Index				Impact Strength	Abrasion Index			
		Average	Min	Max	Average	StDev	Min	Max	Average	Average	StDev	Min	Max
AMPHIBOLITE	160	2,95	2,70	3,37	18,8	4,0	10,9	27,6	1146	0,3465	0,2931	0,0730	1,0756
ANDESITE	246	2,66	2,37	2,88	19,2	4,3	13,1	28,3	1056	0,2723	0,2299	0,0438	1,1355
ANORTHOSITE	50	2,78	2,65	3,09	16,0	3,0	10,5	19,1	922	0,3657	0,0603	0,2688	0,4639
APATITE	43	2,88	2,83	2,95	17,5	4,8	9,5	22,9	1041	0,1009	0,0950	0,0008	0,2463
BASALT	1486	2,86	1,20	3,42	21,7	4,8	9,6	38,6	1283	0,2370	0,1729	0,0152	0,8773
CALCITE	50	2,76	2,69	2,84	7,2	2,8	5,3	12,6	413	19,0446	38,4499	0,0009	95,1716
CONGLOMERATE	43	2,70	2,51	3,05	14,1	4,5	6,1	19,4	795	0,3428	0,2648	0,0621	0,7610
DIABASE	705	2,84	2,58	3,07	19,5	4,3	11,2	31,0	1140	0,2558	0,1497	0,0277	0,8040
DIORITE	298	2,79	2,62	3,04	20,3	5,0	13,4	34,6	1168	0,3830	0,1428	0,0993	0,7736
DOLOMITE	335	2,72	2,15	2,88	13,9	4,1	7,3	21,6	782	0,0253	0,0281	0,0010	0,1210
DUNITE	70	2,91	2,77	3,36	21,2	4,9	14,9	27,0	1260	0,2306	0,1967	0,0379	0,5456
FLINTSTONE	77	2,55	2,18	2,64	13,1	4,4	4,7	18,8	684	0,6558	0,2494	0,1029	0,9532
GABBRO	369	2,91	2,67	3,17	21,5	5,7	11,5	34,9	1289	0,3290	0,1521	0,0506	0,7656

Material Characteristics

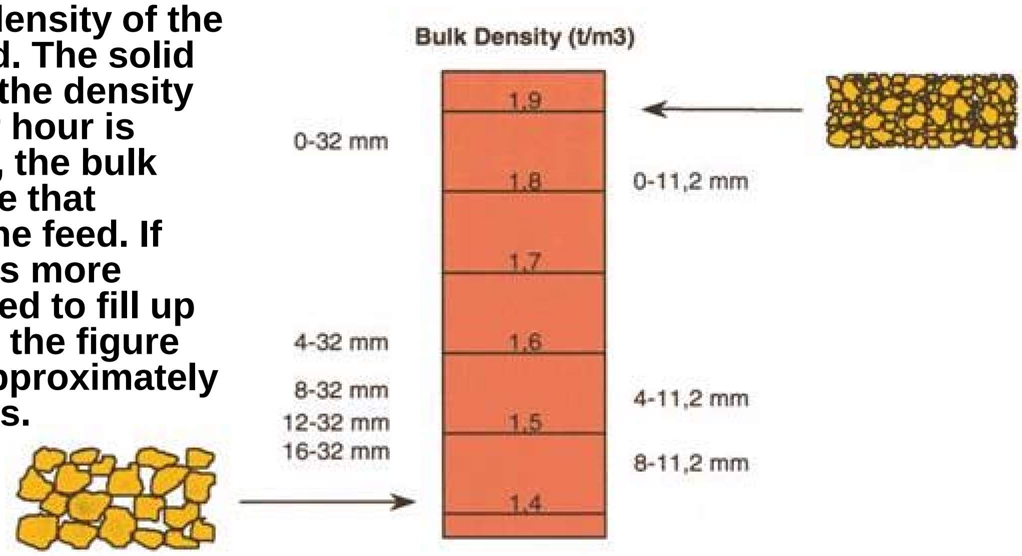


General about Crushing

Capacity

- **In a compressing crusher, the crushing takes place in a crushing chamber with a certain volume. The capacity is then volumetric, i. e. the crusher processes cubic meters per hour. However, the weight is usually of more interest and the capacity is stated as tons per hour. This means that the capacity (in t/h) becomes higher if the bulk density of the feed is increased.**

  The bulk density depends on the solid density of the rock and the size distribution of the feed. The solid density of an iron ore may have double the density of granite, which means that the ton per hour is doubled. If the solid density is constant, the bulk density depends on the amount of space that always exists between the particles in the feed. If the feed size is uniform, there are always more space than if smaller particles are allowed to fill up the rooms between the larger ones. See the figure below. It is valid for a solid density of approximately 2.65 t/m3, which is typical for most rocks.



General about Crushing

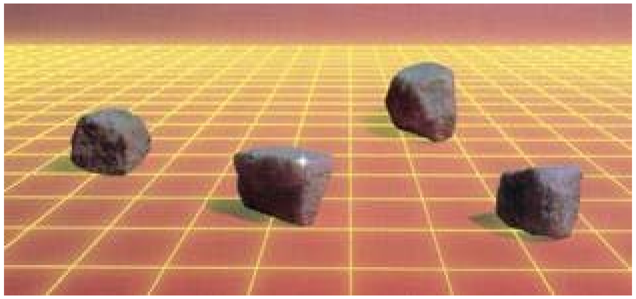
Product shape

- The product shape requirements applicable for material fractions depend on the field of use. Each industry has its own guidelines and standards. Requirements are not limited to the degree of cubicity. They can also cover the surface texture, degree of crushed surface and angularity, for example.

  Asphalt is a flexible material as the binder, the bitumen, is a high viscous oil product. About 95% by weight consists of aggregates. For road construction, high load-bearing capacity is important. The particle shape has a major influence on the strength of the road surface:

- Flaky particles are more easily fractured than compact, cubical particles.
- The rough surface texture and angular shape allow the individual stones to grip each other and give a degree of self-locking.
-

  Concrete on the other hand, is a rigid material when it has hardened. Around 80% by weight, consists of aggregates. The particle shape is important with regard to the characteristics of the wet concrete. The concrete industry appreciates the rounded shape and smooth surface aggregates. The reasons are that a wet concrete based on such a type of aggregates:
- consumes less of the expensive cement binder
- becomes easy to pump
- has a high ability to flow into confined spaces
- has good compaction characteristics.



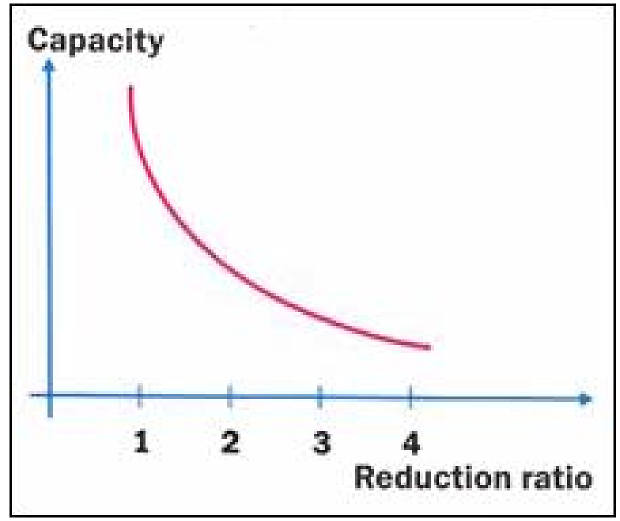
General about Crushing

<u>Reduction ratio</u>

- **After the feed has entered the crusher and travels through the crusher, the crushing chamber volume is decreasing. As the amount of tons coming out must be the same as coming in, the density has to increase. It may reach a level where the amount of space between the particles is so low that it is not possible to compress the material further. This is a crushing state that is called packing. Packing results in very high crushing forces and further reduction is not possible.**

  A high reduction ratio is achieved if the feed has a low bulk density for a start. Fines (which do not have to be crushed anyhow) are usually removed before crushing on this purpose.

  The Impact Work Index, WI, may also limit the reduction ratio. With increasing WI, the crushing force and the related energy consumption for the reduction work is increasing. At a certain reduction ratio the maximum permitted force or motor power level is reached. It should be mentioned that a high reduction ratio can not be obtained with a high capacity. The decreasing volume in the crusher chamber reduces the flow of material.



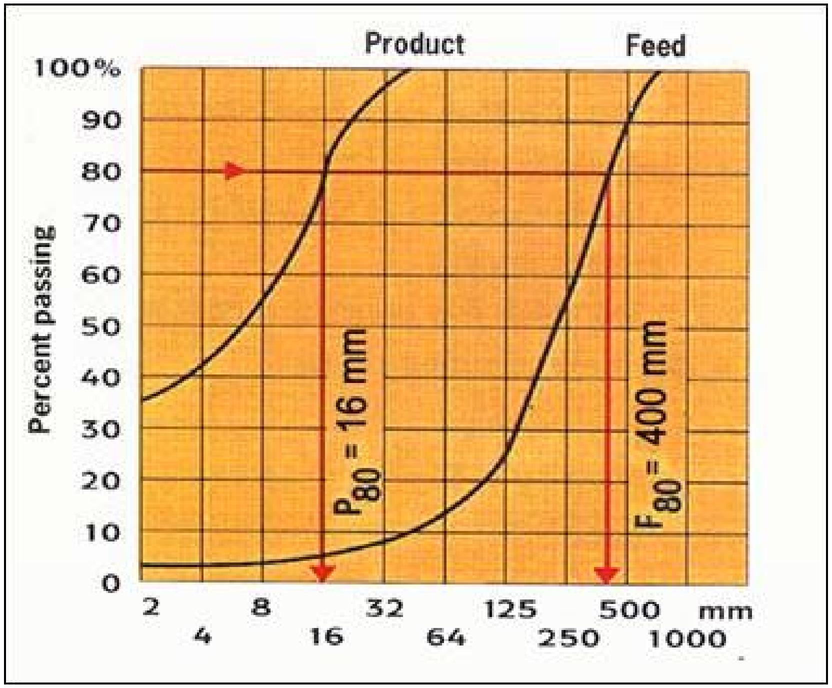
Average Reduction Ratio's "Rules of Thumb"	
Primary Gyratory	3-4
Primary Jaw	2.5-3.5
Primary HSI	7-10
Secondary/Tertiary Cone	3-4
Secondary/ Tertiary HSI	6-8
Tertiary VSI	4

Crushing Stages – Reduction Ratio

- **In a crushing process, the aim is to reduce the size of lumps of material to a certain defined final product.**
- **Ideally, a single machine would be used for this job. It would be able to accept material lumps up to maybe 1 m^3 in size and give a product of perhaps minus 20 mm or even smaller. However, this is not feasible. Every crusher has a certain limited reduction capability. It is therefore necessary to use an appropriate number of crushing stages to reach the required product size. Jaw and gyratory crushers - which we shall focus on - are normally capable of a reduction ratio of 2-3 respectively 3-4.**
- **The reduction ratio is defined as the ratio between the "K80 values" - as they are called - of the material fed to the crusher and the crusher's product. Thus the size which corresponds to 80% (by weight) of the feed to the crusher (F80) should be divided by the size which corresponds to 80% of the crusher's product (P80).**

Crushing Stages – Reduction Ratio

- **This is where the feed to the plant and the desired product must be considered together. The reduction ratio rule of thumb makes it easy to estimate the number of crushing stages needed in a plant.**
- **Example:**
- ***Feed material:* Blasted rock with 80% smaller than 400 mm (i.e. F80 = 400).**
- ***Required product:* Road building aggregates with 80% smaller than 16 mm (i.e. P80 = 16).**
- **The total reduction ratio is:**



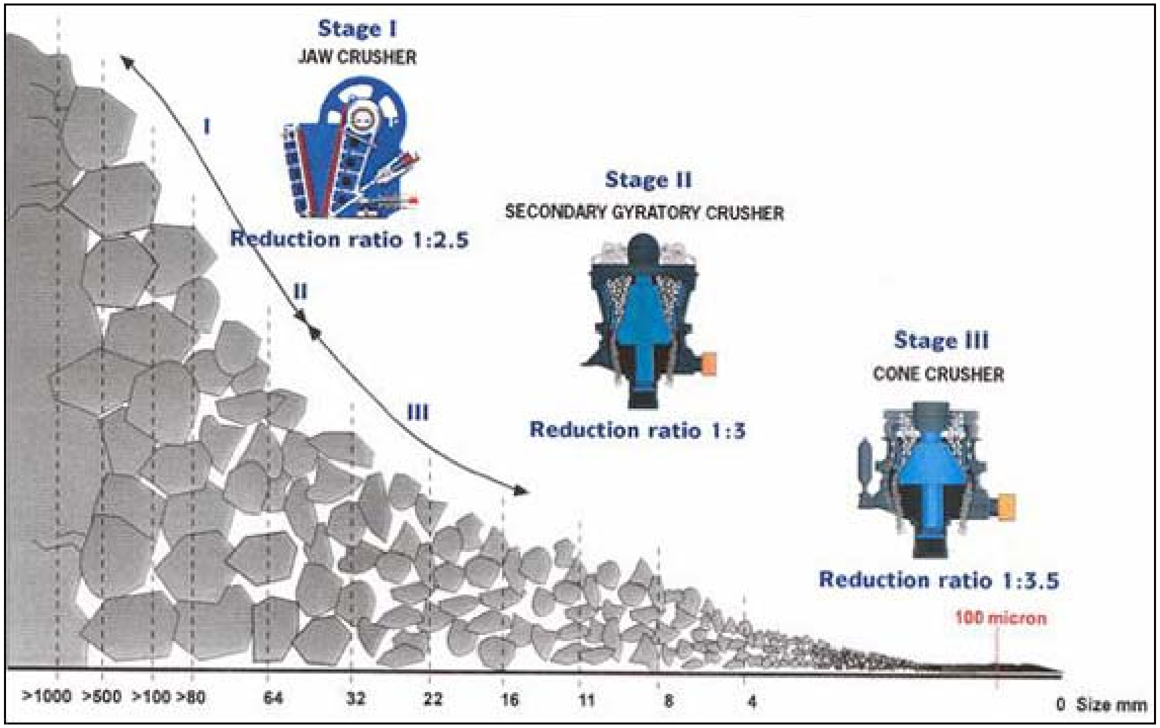
$$R = \frac{F_{80}}{P_{80}} = \frac{400}{16} = 25$$

Crushing Stages – Reduction Ratio

- Reduction ratio in primary crushing stage: R1 = 2.5
- Reduction ratio in secondary crushing stage: R2 = 3
- Together the two crushing stages give a total reduction ratio of R1 x R2 = 7.5

- This is not sufficient, therefore a third crushing stage is required.

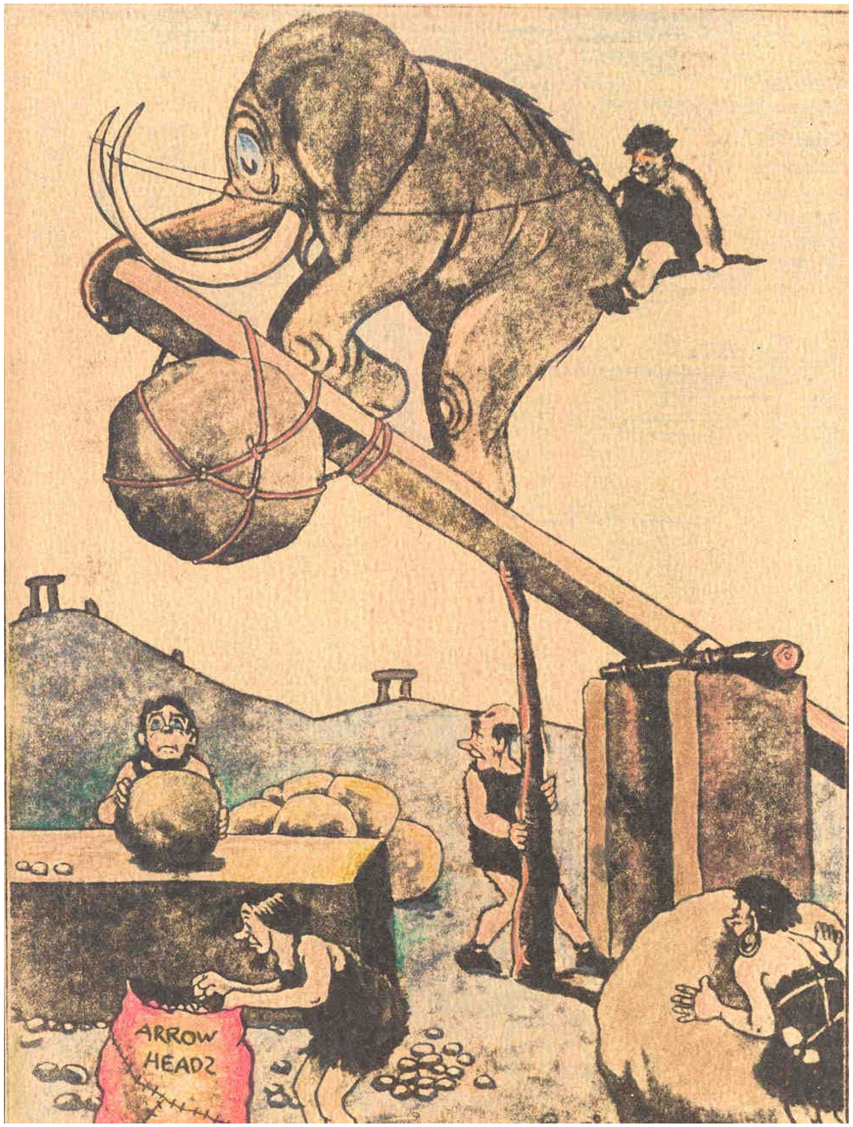
- For example:
  R1 = 2.5
  R2 = 3
  R3 = 3.5

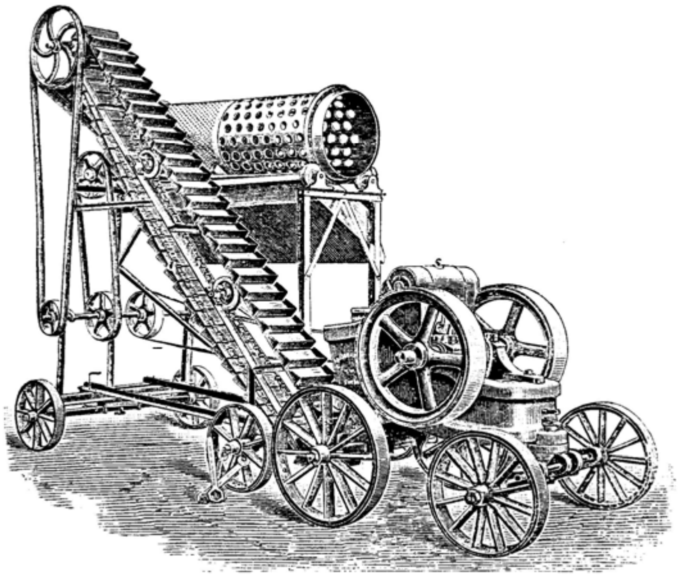


These three crushing stages give a total reduction ratio of:

R1 x R2 x R3 = 2.5 x 3 x 3.5 = 26.

Crusher Types





Crusher Types

Primary type crushers

Capacities:

1800 stph

To

8000 stph

$5^{1}/_{2}$” to 12” OSS

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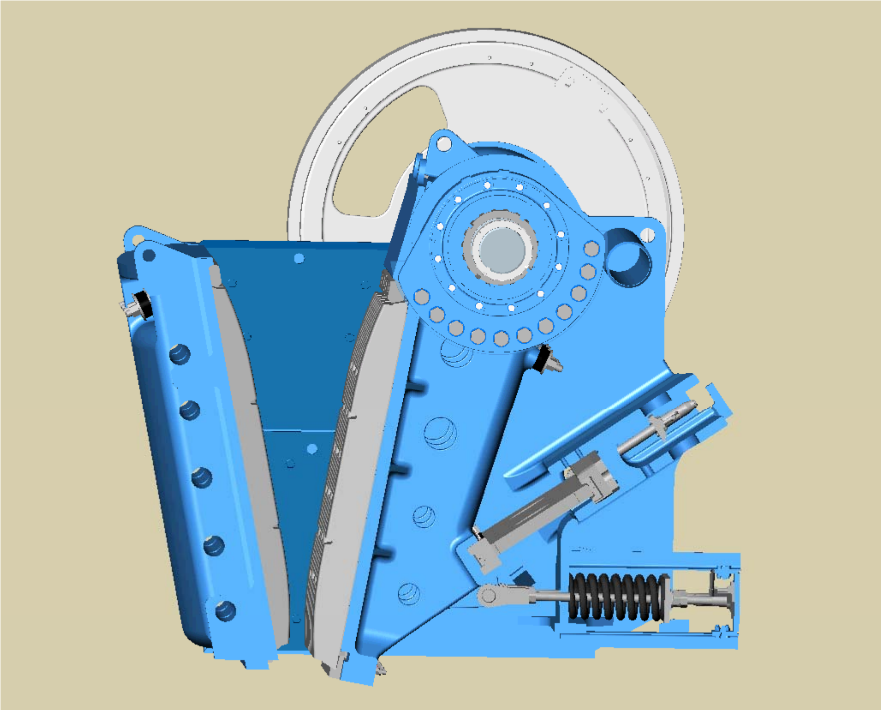
Crusher Types

Jaw Crusher

- **In a jaw crusher, material is crushed between two crushing surfaces - one fixed and one moving. The moving surface - the moving jaw plate - is mounted on a "jaw" which is given a reciprocating motion by an eccentric. The rock to be crushed is subjected to repeated applications of pressure as it passes downwards and is progressively reduced in size until it is small enough to pass out of the crushing chamber.**



Crusher Types

- The jaw crusher does not operate on a continuous basis. This is due to the reciprocating motion of the moving jaw. Crushing only occurs when the moving jaw is moving towards the fixed jaw. No crushing occurs when the moving jaw is receding from the fixed jaw.
- A jaw crusher normally has a "nip angle" (angle between the jaw plates) of between 16 and 26 degrees.
- The discharge setting is adjusted with the use of shims. On larger crushers, this adjustment is made easier by hydraulic cylinders.
- Capacities: 370 stph to 1575 stph (6” – 12” OSS)

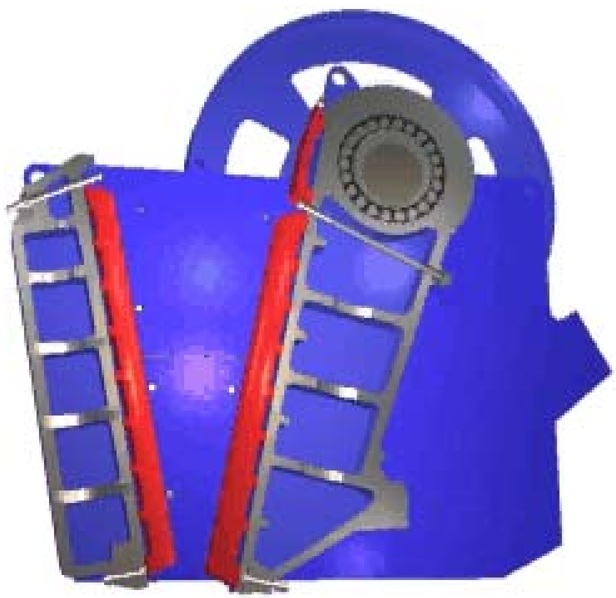
Crusher Types

Single Toggle Jaw Crusher

The moving jaw of a single toggle jaw crusher is journalled directly on an eccentric shaft which provides a circular / elliptical motion.

Double Toggle Jaw Crusher

In contrast, the moving jaw of a double toggle jaw crusher is journalled in the frame and is given a "swinging" motion by two toggle plates and a pitman mounted on an eccentric shaft.



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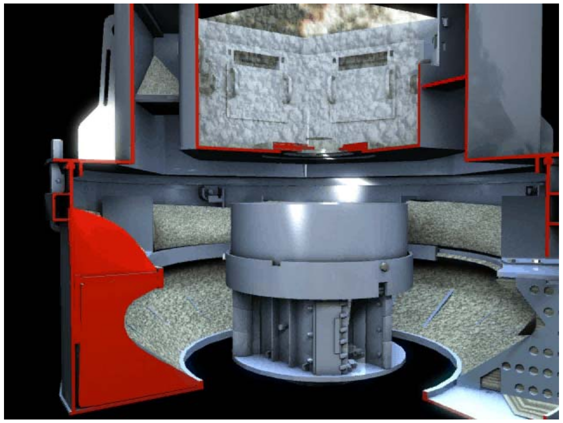
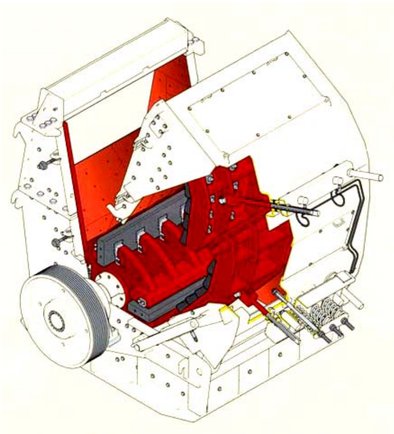
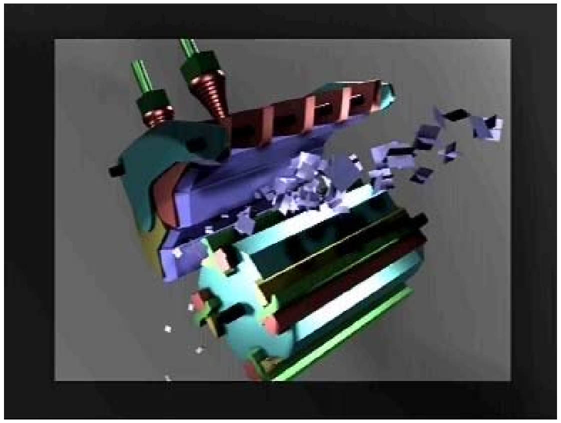
Crusher Types

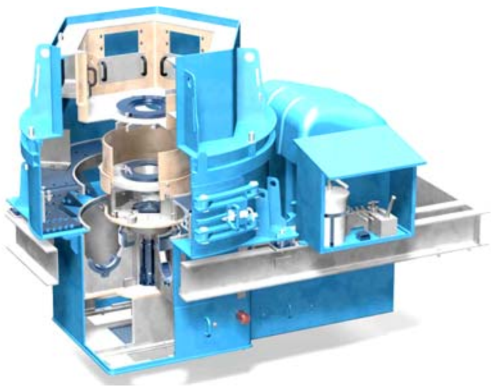
Impactors

- **There are two main types of impact breakers: horizontal shaft impact breakers and vertical shaft impact breakers, sometimes denoted HSI and VSI. Both types are mostly used for reduction of less abrasive materials. Impact breakers are characterized by a simple design with a small number of moving parts.**









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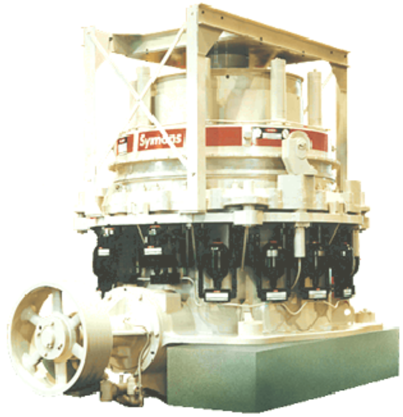
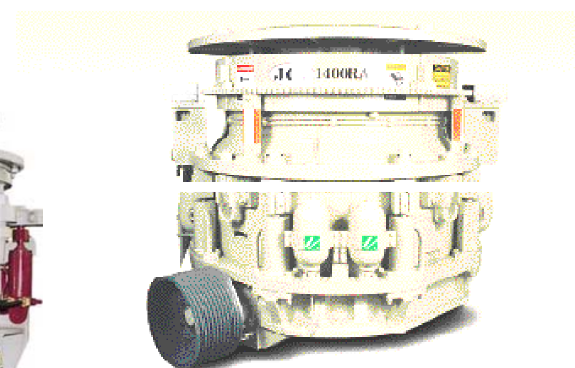


Cone type crushers



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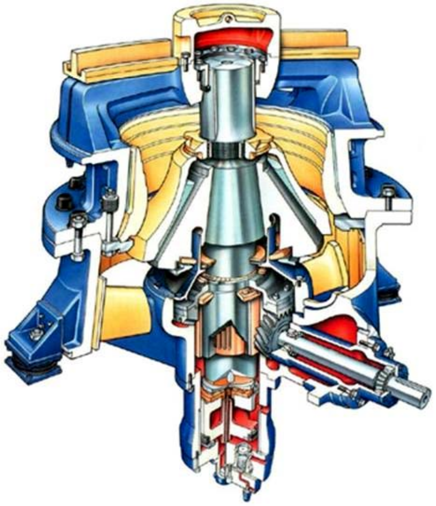
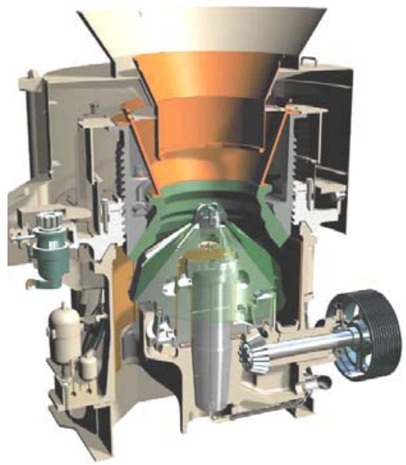
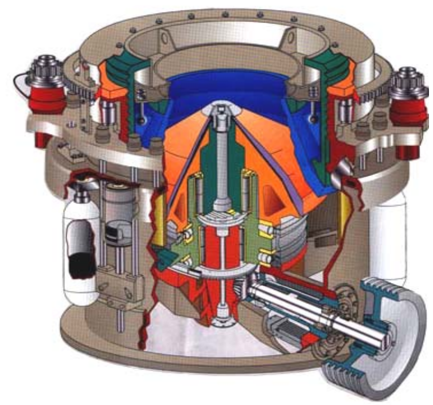
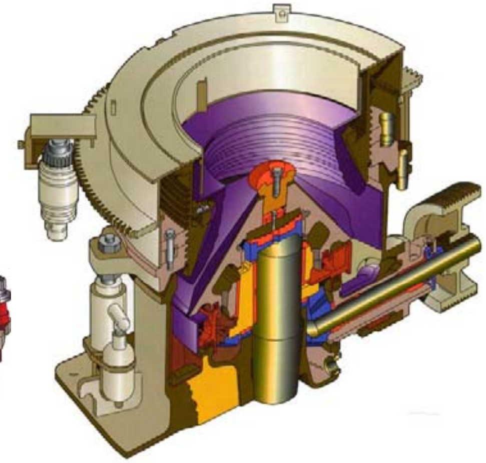
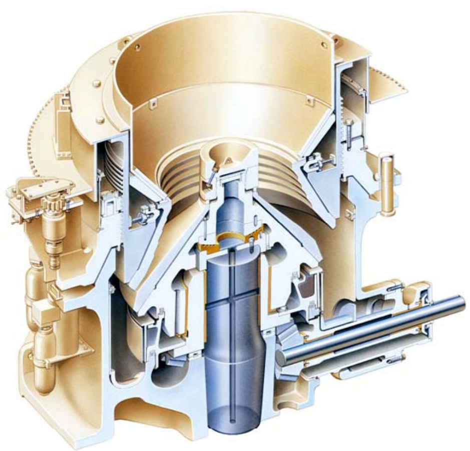


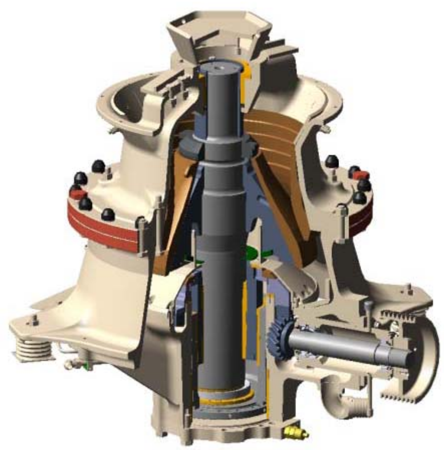


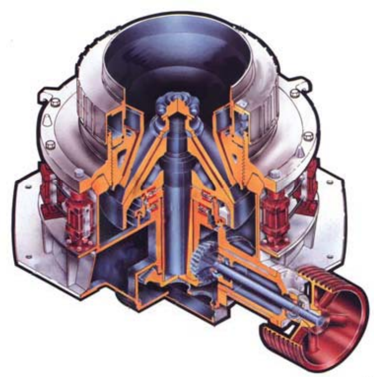


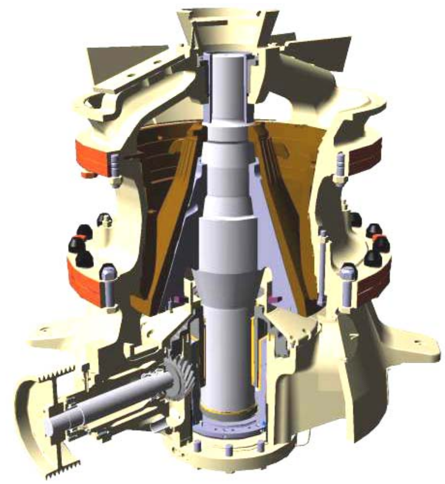


Cone type crushers

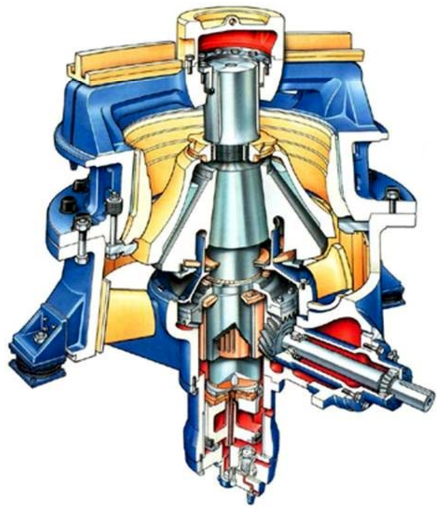






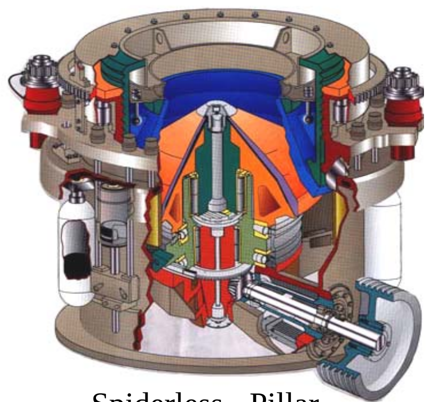


Crusher Types

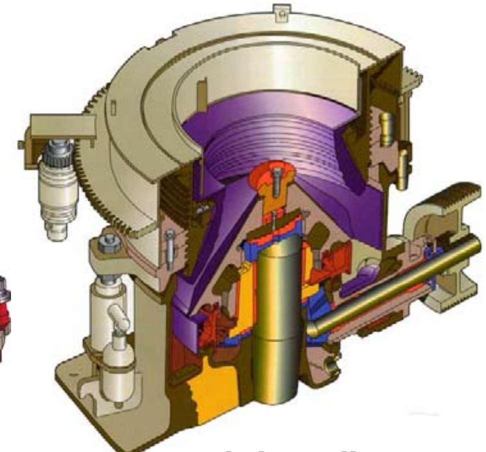


Top Support - Shaft

Spiderless - Pillar

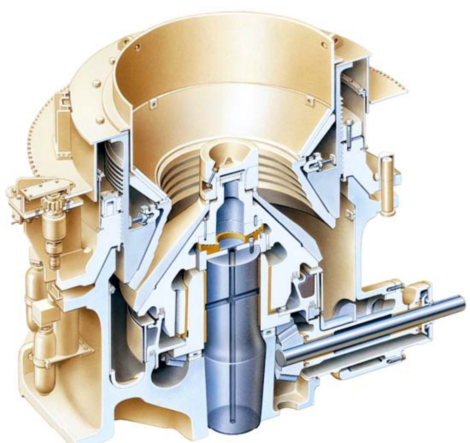


Spiderless - Pillar

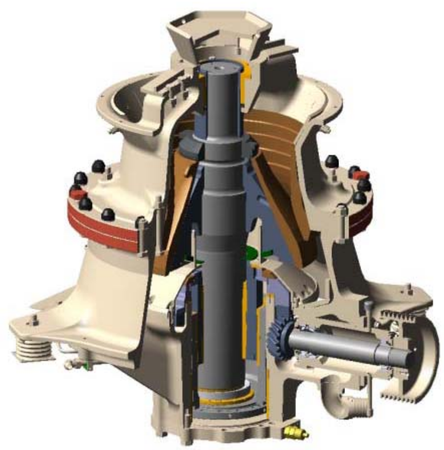


Spiderless Pillar

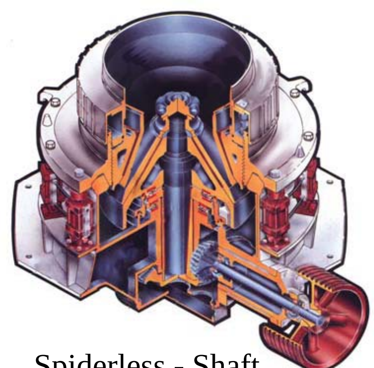
Basically Three types



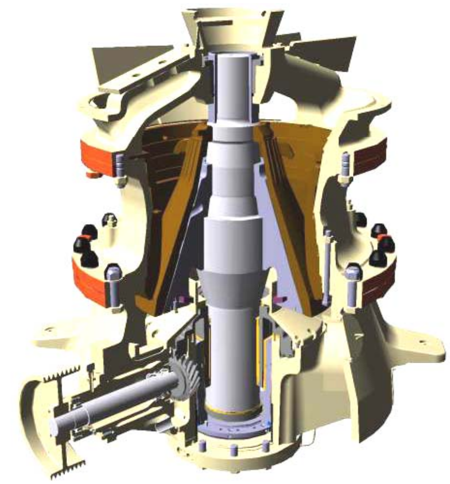
Spiderless Pillar



Top Support - Shaft

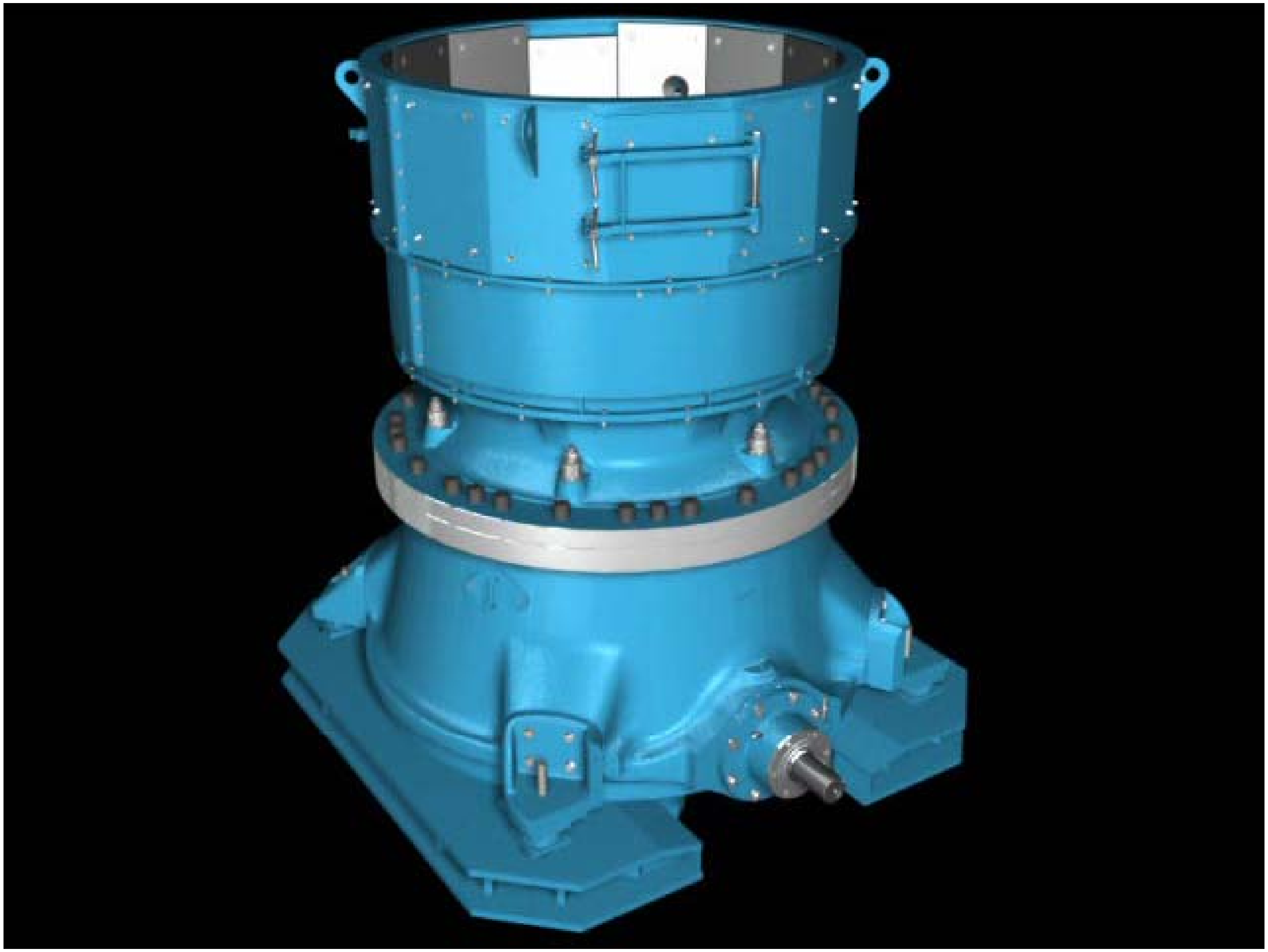


Spiderless - Shaft



Top Support - Shaft

Crusher Types



Feeding Crushers

Feeding of the crusher

- **The feed to a jaw or primary gyratory crusher is irregular by nature but efforts should be made to make the supply as even as possible. Boulders with dimensions close to the feed opening size should be avoided since they can easily reduce the flow of material through the crushing chamber.**

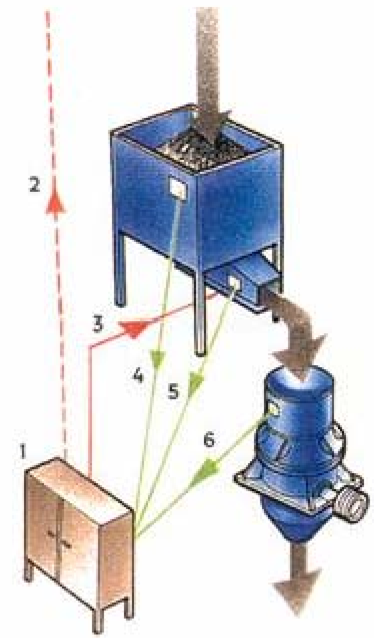
  Cone crushers and secondary gyratories should always be choke-fed. A choke feed condition exists when the entire crushing chamber - up to and above the headnut - is kept full of material at all times. The main reasons are:

  Maximum capacity due to utilization of the full 360 degrees mainshaft gyration.
  High reduction ratio due to efficient interparticle crushing, stone against stone.
  High probability for cubically shaped stones due to the interparticle crushing.
  Consistent product gradation.
  Uniform wear on the crushing surfaces.
  Uniform load on the crusher minimizes the risk for failure.

Feeding Crushers

- The best way to maintain a choke feed is to use a surge bin with a feeder ahead of the crusher plus a level monitor in the crusher's feed hopper.
- Level monitors control the feed to the crusher so that the crusher is either choke fed or idling empty when the supply of material is exhausted.

1. Switch gear unit
2. Stop signal to feeder
3. Control signal to feeder
4. Max. level in surge bin
5. Min. level in surge bin
6. Max. level in crusher feed hopper



Feeding Crushers

- A common disadvantage during feeding is segregation of the feed. This means that the coarser material falls into one place whilst the finer portion of the feed goes to another part of the crushing chamber. The result is that different parts of the crushing chamber do different jobs and the process is limited by the most demanding situation. The overall reduction ratio is lower than normal, the crusher load is varying and the manganese wears unevenly around the chamber. The following picture shows typical segregation in a feed hopper to a cone crusher caused by segregation on the preceding feeder or conveyor.

- Alignment of the top shell arms with the center-line of the feed system enables a distribution to all parts of the crushing chamber. For the finer chambers a distributor with adjustable lead plates is highly recommended.

Feeding Crushers

<u>Crushing in closed circuit</u>

- **If the material passes through a crusher just once (one pass), this is an open circuit. The product size is controlled by the crusher's setting. If a more accurate control of the size is required, the crusher is combined with a screen into a closed circuit.**

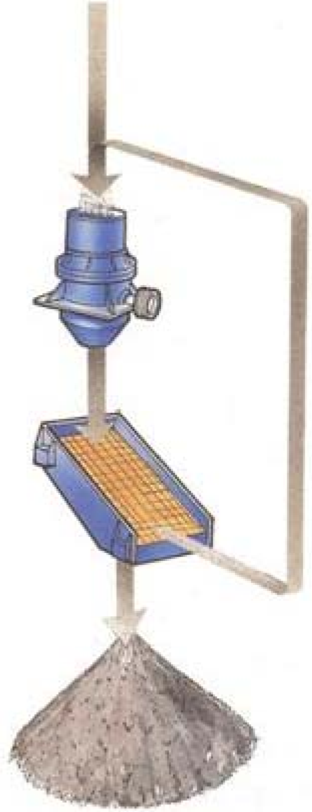
Screening after crushing:

- **Is a common way of combining a crusher and a screen in such a way that the oversize material goes back to the crusher.**

- **This results in a product size controlled by the holes in a screen deck - i.e. in two dimensions. The screening element holes do not vary in size like a crusher setting. The screen sends back to the crusher all material that has not been reduced to a size which can pass through the screen deck. Flat and flaky stones also end up in the recirculated material so that the closed circuit gives a product shape improvement. This arrangement gives what is often called a "calibrated product".**

- **The crusher has to accept the recirculated material and this means that the quantity of "fresh feed" which the circuit can accept is reduced accordingly. If we reduce the hole size on the screen deck, the product will be smaller but the amount of recirculated material will increase. The net capacity of the circuit as a whole will decrease. We obtain higher reduction at the expense of reduced capacity.**

- **However, we cannot reduce the product size too far as the amount of recirculated material will increase and the circuit becomes unstable if the separation size is much smaller than the crusher's C.S.S.**



Feeding Crushers

<u>Crushing in closed circuit</u>

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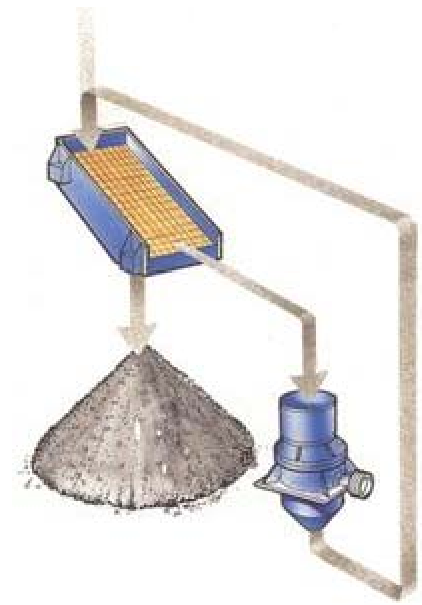


Screening ahead of the crusher:

- can be used to combine a preliminary removal of fine material with a closed circuit. The screen is used in two ways. If we look at this closer we see that it can be considered as a system with two screens.

  If the capacity is such that one screen can handle both jobs, this arrangement is of course preferable. It is both simpler and less expensive. If the capacity is higher we can choose between two parallel screens operating like the single screen shown above or we can use two different screens, where each is adapted to its own duty. The choice is often determined by lay-out

Wear Resistant Materials

- Wear parts for crushers include, amongst other things, mantles, concaves, jaw plates and impellers, all with the same principal feature: They are to withstand the forces created by the interaction between the crusher and the stone material during the moment of crushing service, without being worn out very fast or, even worse, being cracked at the initial stages of the wear part nominal life.
- A number of different materials have been tested, and are in use, in crushers all around the world. The most widely used material types are manganese steels, martensitic white irons and tempered alloyed steels.
- More exotic materials such as cemented carbide and metal matrix composites can be used for special applications.
- Manganese steels can be used for, in principal, all crusher wear parts, however there may be applications where other materials perform slightly better.
- For materials other than manganese steels, the ductility is often very low and therefore, the risk of cracking of the wear parts is high. In the following sections, a thorough review of the properties, benefits and disadvantages of the manganese steels is given. Furthermore, short descriptions of the other material types used for crusher wear part service are presented in the end of the chapter.

Wear Resistant Materials

Manganese steels

History

- **Probably the most widely used material in total for crushers during the last hundred years is a so called "Hadfield steel" with approximately 12 % Mn and 1 % C.**
- **The material was developed in the 1880s by Sir Robert Hadfield and although these materials have been developed substantially since that time as has the production equipment in the foundries casting the wear parts, the principal invention Sir Robert provided with this material, wear resistance by deformation hardening together with good ductility, is today still the feature that makes this type of materials so suitable for crushers.**
- **In order to understand why manganese steels are the preferred choice for many types of crusher applications their different properties have to be reviewed.**

Wear Resistant Materials

Castability

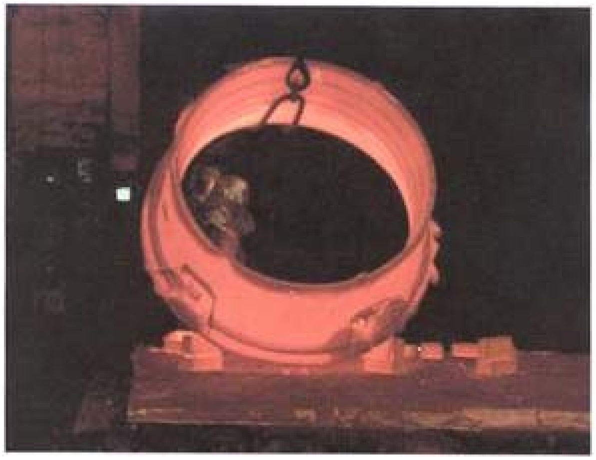
- **The manganese steels used as wear parts in crushers are in the cast and water quenched state.**
- **The castability of manganese steels is good and thanks to the relatively low melting point of the material, the materials are cast at a substantially lower temperature than e.g. carbon- and low-alloyed steels.**
- **Manganese steels have a relatively large interval for solidification, that is the difference in temperature when the material starts to solidify and when this process ends is large, > 100°C. This makes the manganese steels slightly more difficult to cast than e.g. carbon steels and higher requirements regarding process control are therefore set on the foundries casting the wear parts.**
- **Sandvik Rock Processing have experience in casting wear parts for crushers ranging more than 50 years back. Some of the properties of the manganese steel are actually determined already during casting.**
- **The higher the cooling rate in the cast part, the finer grains and the better possibilities to achieve good properties when it comes to strength and toughness. The grain growth during heat treatment and water quenching is low and the rate of crystallisation is minimal and thus a coarse microstructure after casting cannot be made finer at the later stages.**
- **Fast cooling rate and low casting temperature are beneficial for fine grain size in the manganese steels.**

Wear Resistant Materials

Heat treatment

- **For most applications, *including crusher* wear parts, manganese steels have to undergo a heat treatment and water quenching procedure after casting. This is owing to the fact that during solidification and cooling in the mould, carbides are precipitated to a wide extent which make the material very brittle without ability to withstand impact stress without cracking. The materials are therefore slowly heated up to approximately 1100°C at which temperature the material is kept to get all through heated in order to dissolve the carbides. When quenching the hot cast parts in water, the cooling of the steel is so fast that the carbides stay dissolved in the material. Some carbides are in any case precipitated but now evenly distributed, which do not make the material brittle and actually increase the wear resistance of the material. It is important to point out that the microstructure never can be totally free from carbides. There are a number of different factors determining the residual amount of carbides in the manganese steels among which the thickness, the chemical composition and the heat treatment temperature are the most important ones. The thicker the part, the lower the cooling rate in the centre of the material and the higher the risk of grain boundary carbides. Manganese steels have very low thermal conductivity which is a disadvantage in this respect and actually limits the maximum thickness of the materials to be cast. Parts thicker than 150 mm are seldom used.**
- **Higher content of some carbide forming elements such as e.g. Cr, Ti and V make the carbide formation during cooling faster. For alloys with high manganese and chromium content, the maximum possible thickness for cast parts is lower than the 150 mm mentioned above for most available alloys.**

Wear Resistant Materials



Machinability

- **Some wear parts, as e.g. mantles and concaves for gyratory crushers, have contact surfaces that need to be machined to narrow tolerances for best possible crusher service.**
- **The machinability of manganese steels is bad but Sandvik Rock Processing have, thanks to our long experience in machining of this alloy type, no problem meeting the tough requirements set.**
- **The machining is carried out by using cemented tungsten carbide or cubic born nitride tools. When a drill or cutting tool is applied a manganese steel quickly work-hardens the area to the extent that this type of machining becomes very difficult.**

Wear Resistant Materials

Mechanical properties

- Manganese steels have relatively good mechanical properties, such as toughness and strength, but generally with slightly lower yield strength than have carbon and alloyed steels.
- In Table 1 below the mechanical properties of manganese steels are summarized. However, the manganese steels have a much better ductility when compared with most other cast materials. This fact makes the materials in question suitable for service demanding good performance under loads above the yield point. The ductility is decreased in thicker sections.
- Another very important feature is the deformation hardening mechanisms. By this is meant that the materials get harder as the uppermost layer of th wear parts are deformed by the crushing forces, increasing the wear resistance during service. This results in a hardness gradient through the wear part piece, with the highest hardness at the crushing service. As the wear part starts to be worn, this hardness gradient starts moving inwards.
- When put into service, the hardness of the material is approximately HB 200 and after service, surface hardness values above HB 400 are not uncommon.
- The hardness of the contact surface of the wear piece, i.e. opposite the crushing surface, will in principal stay unaffected all through the part's life. Another important and very advantageous property of manganese steels is the very low crack propagation rate. Sooner or later during service small microcracks will be initiated in the material but thanks to the low propagation rate, the part is normally worn out before it is cracked.

Yield strength	350
MPa Tensile strength	750 - 900
MPa Fatigue limit	270
MPa Elongation	35 - 45 %
Hardness as quenched	HB 200

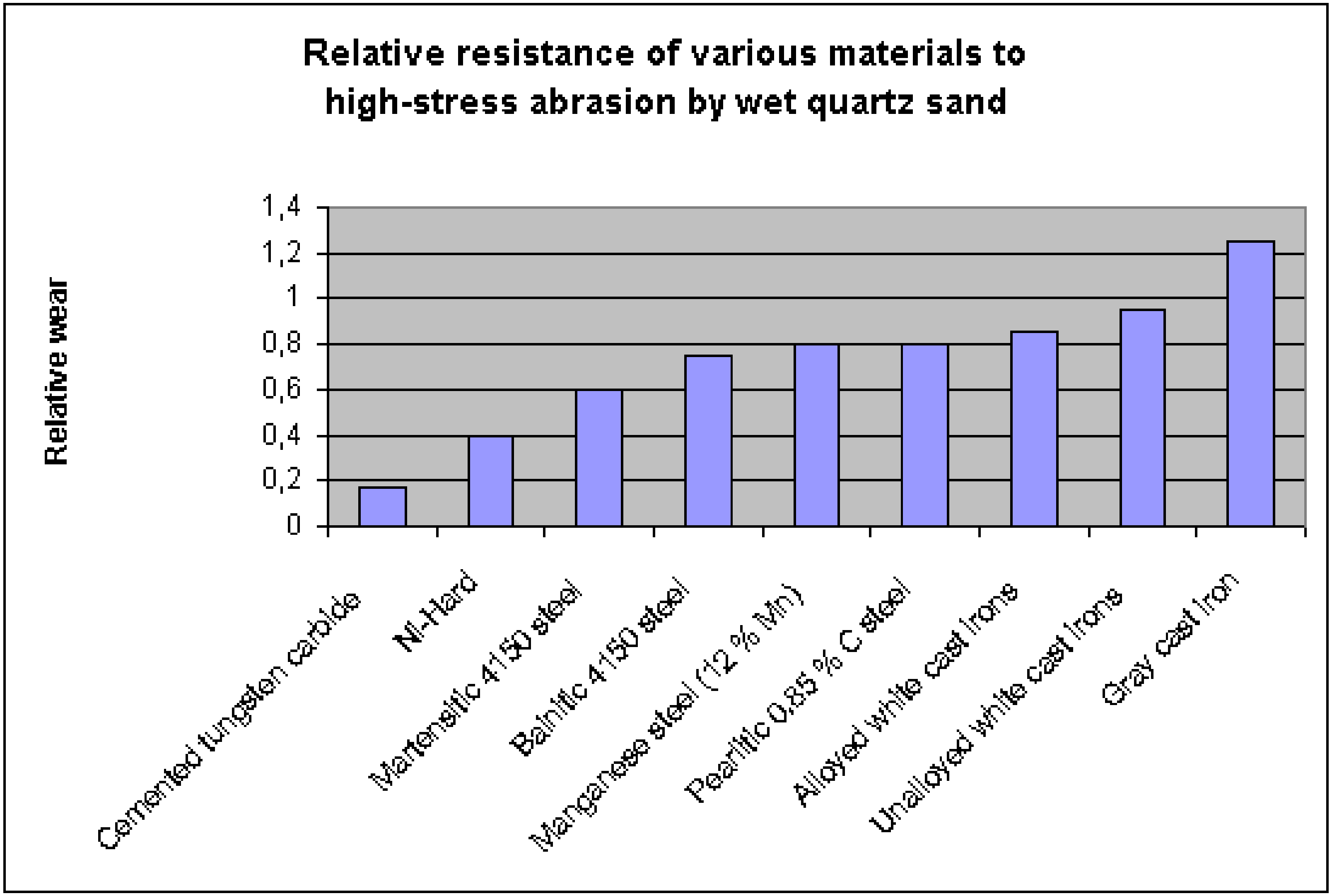
Table 1: Mechanical properties of manganese steels (normal values)

Wear Resistant Materials

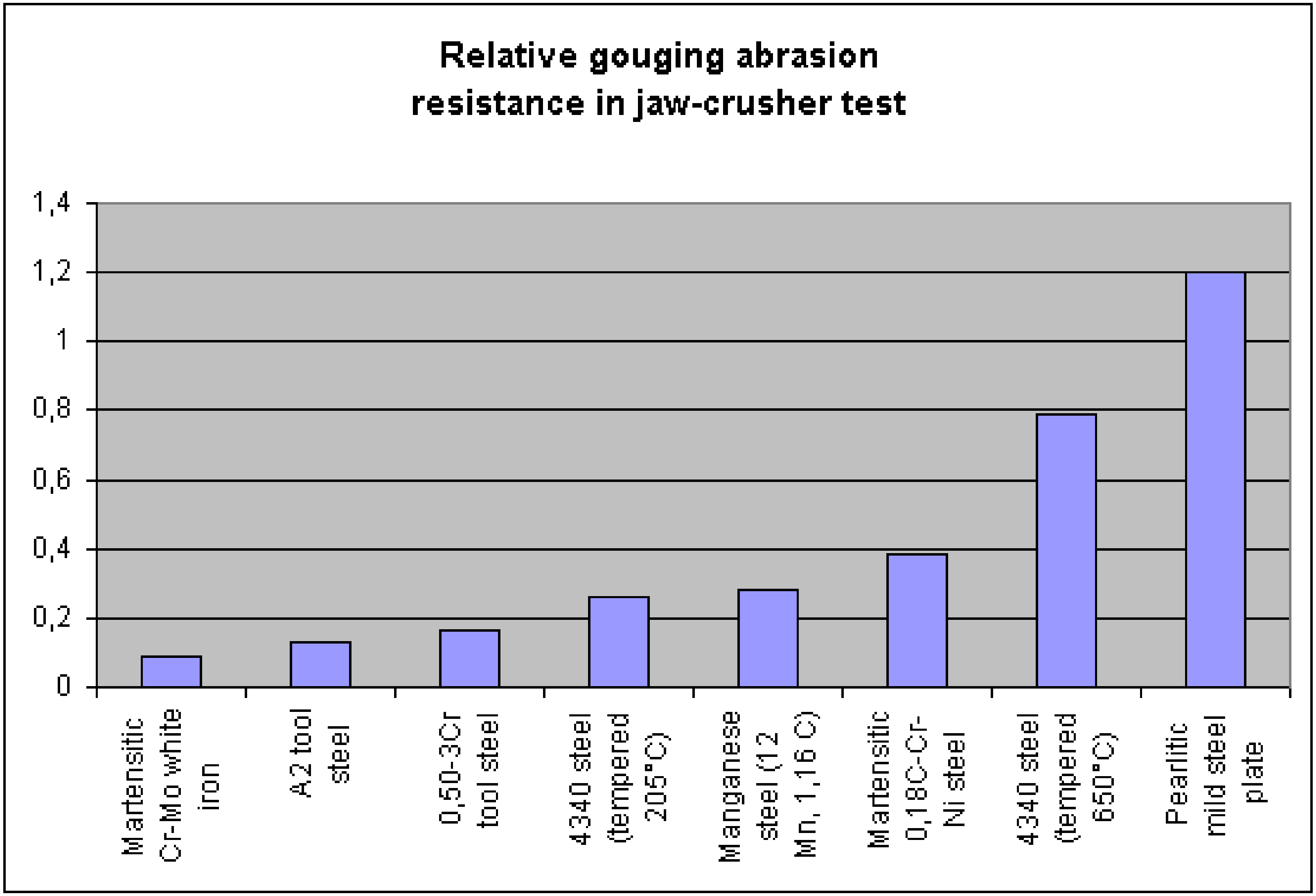
Wear

- **Manganese steels are wear resistant thanks to the above mentioned deformation hardening mechanism. A certain impact force is needed before the material reaches its wear resistant state. The more impact and hammering it receives, the harder the surface becomes. This characteristic, plus the fact that it remains ductile underneath, makes it a most effective steel in combating impact and abrasion. A very soft material to be crushed can thus be worse for the manganese steels than hard materials. If the stone material is too soft, sufficient work-hardening is not achieved and the manganese stays in the as-quenched state with low wear resistance.**
- **Manganese steels are cheaper and much more ductile than most other iron-based alloys used as wear resistant materials. Normally the wear resistance is lower than for martensitic white irons and martensitic steels with high carbon content but these materials' brittleness make them unsuitable for many crusher applications. The wear resistance of manganese steels is normally higher than that of pearlitic white irons and pearlitic steels.**
- **The wear resistance is dependent on the type of wear the materials is subjected to but as a general rule can be said that manganese steels have good abrasion and gouging resistance whereas the erosive wear resistance is bad and sliding wear resistance is very much dependent on the special conditions of the sliding wear system. In the figures below two examples of results from different abrasion wear tests with manganese steels and other alloys are presented.**

Wear Resistant Materials



Wear Resistant Materials



Wear Resistant Materials

Different types of manganese steels

- **There are many different types of manganese steels available today. However, they can be roughly divided into three main groups, depending on their manganese contents:**
- **low manganese steels (roughly 6-8 % Mn)**
  ordinary manganese steels (roughly 10-14 % Mn)
  high manganese steels (above 16 % Mn)
- **The low manganese steels are not used to a wide extent and for in principal all crusher applications ordinary or high manganese steels are more suitable. Sandvik Rock Processing have two main alloys, M1 and M2, of which the first one belongs to the ordinary manganese steels and the latter one belongs to the high manganese steel group. M1 is the one that can be chosen for most applications but with easily crushed but very abrasive stone material to be crushed, M2 is a better choice. Thanks to the higher manganese content it is possible to dissolve a higher carbon content in the material, which in turn makes the material more abrasion resistant. On the other hand, M2 is more crack sensitive thanks to its lower ductility, especially for thick cast sections.**

Wear Resistant Materials

Martensitic cast white irons

- High-alloyed white irons, heat-treated to achieve a martensitic microstructure, have excellent resistance to gouging abrasion and outperform most other wear resistant materials in this aspect. However, these alloys are very brittle and the risk of cracking is thus very high. For applications including high impact loads the use of cast white irons is therefore limited. If the wear parts crack and come loose, there is a risk of damaging the equipment used (both the crusher and the following units). Trials have been made to armor cast white iron wear parts in order to prevent the loosening of parts even though they crack. By doing this the wear part can keep its functionality (the wear resistance has not been harmed) for a prolonged period of time.
- Martensitic white cast irons may be used for some jaw and gyratory crusher plates where high abrasion resistance is required and ductility of the wear part is not of prime interest. Impact bars for impact crushers have also successfully been equipped with white iron as wear material.
- Martensitic cast white irons can not be used for cone crusher mantles. The lack of ductility is one reason for not using the materials but the martensitic white cast irons also have two other disadvantages in their hardened state (i.e. in the condition they are used in the crusher): they can neither be machined by conventional methods, nor can they be welded. Traditionally three different types of white irons have been used for wear parts:

  25Cr alloys

  15Cr - 3Mo alloys

  4Ni - 2Cr alloys (Ni-Hard)

Wear Resistant Materials

Alloyed steel

- **First of all, there is no sharp limit between low-alloyed steel and alloyed steel and neither is there a sharp limit between alloyed steel and high-alloyed steels. However, most steels (except for manganese steels) that are used for crushing service are alloyed with Cr and/or Ni and or Mo in varying amounts. The alloying elements are added primarily to control hardenability of the materials. The alloyed steels are hardened by different heat treatment procedures (differing from manganese steels that are hardened under the impact of load). A key benefit of using alloyed steels is that the properties of the materials can be varied by applying different heat treatment procedures to the cast pieces, and still keep the same alloy. One typical application therefore is concaves for gyratory crushers, where the top row must have a certain amount of impact strength and not necessary very good wear resistance whereas for the lower rows the need for wear resistance is increasing. As with martensitic cast white irons, the possibilities to machine and weld the hardened alloy steels is very limited.**

Wear Resistant Materials

<u>Cemented carbide</u>

- **One of the materials known to have the best wear resistance is cemented carbide, that mainly are used as very small parts for tooling. The material consists of tungsten carbides in a cobalt matrix. These materials are extremely brittle and can not withstand any forces created by tension or bending. They are also very expensive to produce, especially in bigger sizes and these limitations together make them therefore not possible to use for most crusher applications. However, for vertical shaft rock-on-rock impact crushers, the wear tip may use cemented carbide as wear part.**

Wear Resistant Materials

Metal matrix composites

- **By metal matrix composites (MMC) is meant a material consisting of at least two parts, which have different properties. By having that, it is e.g. possible to combine a ductile matrix with hard particles for better wear resistance. A number of different such materials have been seen for crusher wear parts including different cast irons and steels with the addition of titanium carbides or aluminum oxide particles. However, their expensiveness and their bad machinability make them difficult to use for many applications. Possibly impact bars are the most likely product for these type of materials.**
- **Compound materials**
  Compound materials consists of at least two materials, but not mixed together as with the MMCs but in different sections or layers of the wear part. The idea is often to apply a hard coating to the crushing surface and keeping the ductile, machinable material for the contact surfaces toward e.g. the shell of the crusher. The coating can be applied by different techniques including welding and plasma spraying but it is difficult to get the layer sufficiently thick to get a substantially longer wear life of the part as compared with e.g. a non-coated manganese steel, and thus cost-effective. These type of materials have been produced for e.g. roller crushers.

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