S. ŽIC, I. DŽAMBAS, M. IKONIĆ

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POSSIBILITIES OF IMPLEMENTING BIMETALLIC HAMMER CASTINGS IN CRUSHING INDUSTRIES

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For decades manganese steel casts have been most used materials for manufacturing elements subjected to impact and high stress abrasion. These materials are used in countless industrial applications that involve crushing of raw material by impact. Some of most important characteristics of manganese cast steels are work-hardening and high strength. Opposite from manganese steels, highly alloyed white cast irons are materials with high amount of hard carbide phases that shows better abrasion resistance but have lower strength and impact energy. Aim of this paper is to investigate possibilities to reduce costs and maintenance periods by implementing bimetallic materials.

Key words: manganese steel, white cast iron, abrasive wear, strength, hardness

Mogućnosti primjene bimetalnih ljevova u procesu usitnjavanja. Manganski čelični ljevovi su desetljećima najkorišteniji materijali za izradu elemenata izloženih kombinaciji udarnih opterećenja i jake abrazije. Svoju primjenu imaju u brojnim industrijskim procesima koji uključuju udarno usitnjavanje materijala. Neke od najbitnijih karakteristika ove grupe materijala su visoka čvrstoća i otvrdnjavanje radom pod djelovanjem udarnih opterećenja. Nasuprot njima, visoko legirani bijeli tvrdi ljevovi su materijali vrlo visoke makro tvrdoće sa značajnim udjelom tvrdih krom karbida. Cilj ovog rada je istražiti mogućnosti primjene bimetalnih materijala čime bi se smanjili troškovi i trajanje održavanja.

Ključne riječi: manganski čelik, bijeli ljev, abrazivno trošenje, čvrstoća, tvrdoća

INTRODUCTION

Numerous industries involve impact crushing of raw material in their processes. Crushing is performed by interaction between raw material witch size is reduced during this process and equipment or parts that crush.

Some of the biggest and most important clients of crushing and milling equipment are industries like cement plants, mines, open pits, coal fired thermal plants, recycling and shredding industries and rock processing plants.

In the crushing process, size of particle is reduced by fracturing them. When the local strain energy exceeds a critical level, which is a function of the material, fracture occurs along lines of weakness and the stored energy is released. Some of the energy is taken up in the creation of new surface, but the majority of it is dissipated as heat. The force applied may be compression, impact, or shear, and both the magnitude of the force and the time of application affect the extent of grinding achieved. For efficient grinding, the energy applied to the material should exceed, by as small a margin as possible, the minimum energy needed to rupture the material. Excess energy is lost as heat and this loss should be kept as low as possible.

S. Žic, I. Džambas, M. Ikonić, Faculty of Engineering, University of Rijeka, Rijeka, Croatia

Wear is a phenomenon caused by moving surfaces and their interaction, which cause material loss from the surface. Depending on the type of raw material (its hardness and particle size), desired reduction rate and capacities optimal process of resizing can be chosen.

Operating costs of crushing plant is in correlation with consumed energy which, further on, depends on ratio of particle size before and after crushing process. Besides that, reliability of crushing plant and high productivity with lower maintenance costs greatly depends on type and quality of crushing elements.

CONSUMPTION OF ENERGY IN CRUSHING PROCESS

All types of crushing process are very inefficient in terms of energy consumption. Degree of efficiency can be calculated by Eq. (1) [1]:

$$\eta = \frac{\text{Energy for surface creation}}{\text{Energy apsorbed by material}} = e_s \, \frac{A_2 - A_1}{W_n} \tag{1}$$

where e_s is the surface energy per unit area and W_n is the energy absorbed. Crushing efficiency ηc is very low, usually below 5%.

Minimum energy required for given reduction process is not easy to calculate. Empirical laws unified in differential form proposed for calculations are shown in Eq. (2).

$$d\left(\frac{W}{m}\right) = -\frac{d\overline{D}_s}{\overline{D}_s^n} \quad (2)$$

$\overline{D}_s$ is the surface volume diameter, k and n are constants and m is mass of material being ground.

Three main laws, named by their authors, define amount of energy needed for crushing of particles.

Kick [1] assumed that the energy required to reduce a particle size was directly proportional to the size reduction ratio (n=1).

$$\frac{W}{m} = K_K \ln\left(\frac{\overline{D}_{sa}}{\overline{D}_{sb}}\right) \text{ Kick's law} \quad (3)$$

Where K_k is Kick's constant and subscripts a and b refer to the initial and final states.

Rittinger [2], assumed that the energy required for size reduction is directly proportional, not to the change in length dimensions, but to the change in surface area. This leads to a value of 2 for n

$$\frac{W}{m} = K_R\left(\frac{1}{\overline{D}_{sa}} - \frac{1}{\overline{D}_{sb}}\right) \text{ Rittinger's law} \quad (4)$$

where K_R is called Rittinger's constant.

Bond [2] has suggested an intermediate course, in which he postulates that n is 3/2 what leads to:

$$\frac{W}{m} = K_B\left(\frac{1}{\sqrt{\overline{D}_{80b}}} + \frac{1}{\sqrt{\overline{D}_{80a}}}\right) \text{ Bond's law} \quad (5)$$

where $\overline{D}_{80}$ is particle size such that 80% by weight of the sample is smaller than it [1].

TYPES OF CRUSHING EQUIPMENT

Several types of crushing machines are used in aggregate processing. Two main groups are compression type crushers, such as jaw and cone crushers and impact type crushers, such as bar blow crushers or vertical shaft impactors. Main groups and characteristics of these machines are shown in Table 1.

Table 1. **Types of crushing equipment**

Type	Hardness	Reduct. ratio	Main use
Cone crushers	Medium hard to very hard	1:8	Granite, basalt, hard rock, limestone, different types of ore
Gyratory crushers.	Soft to very hard	1:6	Rock, gravel, different kinds of ore and other hard materials
Hammer mills	Medium hard to very hard	1:20	Coal, coke, limestone, gypsum, different types of ore and salt
Horiz. shaft impactors	Soft to medium hard	1:20	Quarried materials, sand , gravel
Impact crushers	Medium-hard and hard	1:20	Limestone, gypsum, potash, overburden, slag
Jaw crushers	Soft to very hard	1:7	Quarried materials, sand , gravel
Lump crushers	Soft to medium-hard	1:40	Fertilizer, salt, chemical products
Roll crushers	Soft to medium-hard	1:6	Coal, limestone, gypsum, slag
Vert.shaft impactors	Medium hard to very hard	1:6	Sand, gravel

Hammer mills

Hammer mills consists of a horizontal rotor with hammers attached, spinning at high speed within a chamber lined with breaker plates. The feedstock enters at the top of the chamber and goes through a discharge plate at the bottom when crushed to the desired size. Simplified construction of hammer mill is shown on Figure 1. The rotor spins at between 750 and 1800 rpm. Raw material is broken by the combination of direct impact by the hammers, impact with the breaker plates lining the chamber and impact with other particles of the feedstock.

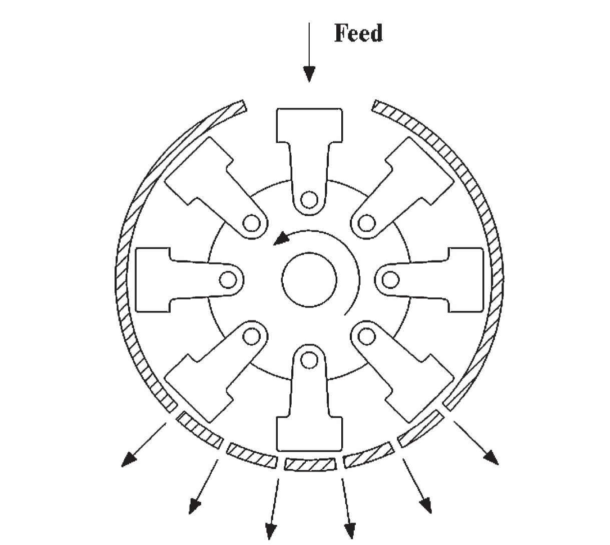

Figure 1. Construction of hammer mill equipment

MATERIALS IN HAMMER MILL APPLICATIONS

Manganese steel

Most common material used for casting crusher hammers is manganese steel. Austenitic manganese steel, containing about 1.2%C and 12%Mn, was invented by Sir Robert Hadfield in 1882. Typical chemical composition of this material is shown in Table 2. It combines high toughness and ductility with high cold work ability and good resistance to wear. It is still used extensively, with composition and heat treatment modification, primarily for parts for dredgers and crushers, crushing jaws or impact wedges.

However, using austenitic manganese steel in applications that doesn't involve crushing of very hard and large sized particles like rocks is not the best application, because in this case, cold work hardening cannot happen. In this situation, manganese steel shows slightly better abrasion resistance than mild steel.

Table 2. **Composition and Brinell hardness of Hadfield steel / in wt.%** [3]

C	Si	Mn	Cr_{max}	P_{max}	S_{max}	HB
1.2	0.5	12	1.5	0.1	0.04	˜ 200

Chromium cast iron

Since the invention of Hadfield steel, many other abrasion resistant materials were created. Some of them like ceramics shows extreme abrasion resistance but low toughness and can't be used in applications that involve crushing by impact [4].

Chromium white iron is group of cast materials with high chromium content (1-35%), and carbon content between 2 and 4%. Hardness of chromium white irons is usually higher than 60 HRc hardened by the formation of hard alloy carbides chromium rich M_7C_3 chromium carbides with hardness up to 2000 HV. The dispersion and the quantity of carbides through material increase its hardness and abrasion resistance. Some standards for laboratorial testing of abrasional resistance are shown in Table 3.

Table 3. **List of ASTM standards concerning abrasion wear** [5]

Standard	Description
ASTM G 65	Test method for measuring abrasion using the dry sand/rubber wheel apparatus.
ASTM G 75	Test method for determination of slurry abrasivity and slurry abrasion response of materials.
ASTM G 81	Test method for jaw crusher gouging abrasion test.
ASTM G 105	Test method for conducting wet sand/rubber wheel abrasion tests.
ASTM G 132	Test method for pin abrasion testing.

Although laboratory tests don't always show same abrasion resistance like real experimental work, they can roughly predict wear resistance of tested alloys. Difference in wear resistance between white chromium cast iron and manganese steel, show that white chromium group of irons have about nine times better abrasion resistance (tested according to ASTM G81 standard) than austenitic manganese steel [6].

Manufacturing price of white chromium cast irons is about 30% higher than manganese steel manufacturing price. However, chromium white irons have much lover toughness and cannot be used without additional preparations for machine parts subjected to high impact loads.

BIMETALLIC HAMMERS

Limits of wear resistance by using mono-metallic alloys have been reached. Wear becomes significant cost factor not only due to repurchasing and changing wear parts but also due to shutdown times.

Next step in manufacturing wear resistant parts is to manufacture bimetallic elements that can withstand high impact loads and have abrasion resistance of highly alloyed white chromium iron [7].

Patented technology, shown on Figure 2, provides risk free operation with highly wear and impact resistant chromium cast iron is used in impact parts of hammers and combined with Cr-Mo alloyed tempered steel.

This technology allows usage of hammers in hammer mill plant in weight range up to 150kg simultaneously combining abrasion resistance of chromium white iron with hardness up to 64 HRc and toughness of 28 – 32 HRc alloyed tempered Cr-Mo steel. Metallurgy and hardness of bimetallic hammer castings is shown on Figure 3.

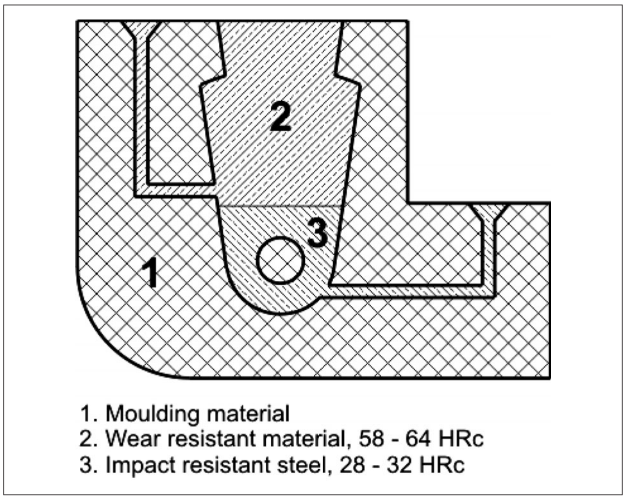

Figure 2. Principle of molding bimetallic hammers [7]

EXPERIMENTAL WORK

Comparison test was performed in a dolomite quarry in the Harz region of Germany. Hammers were mounted in the center of the rotor and compared to the conventional hammers from manganese steel using mass loss technique. Hammer mill with six bimetallic and 18 monometallic cast hammers were utilized to crush 4500t of feed material.

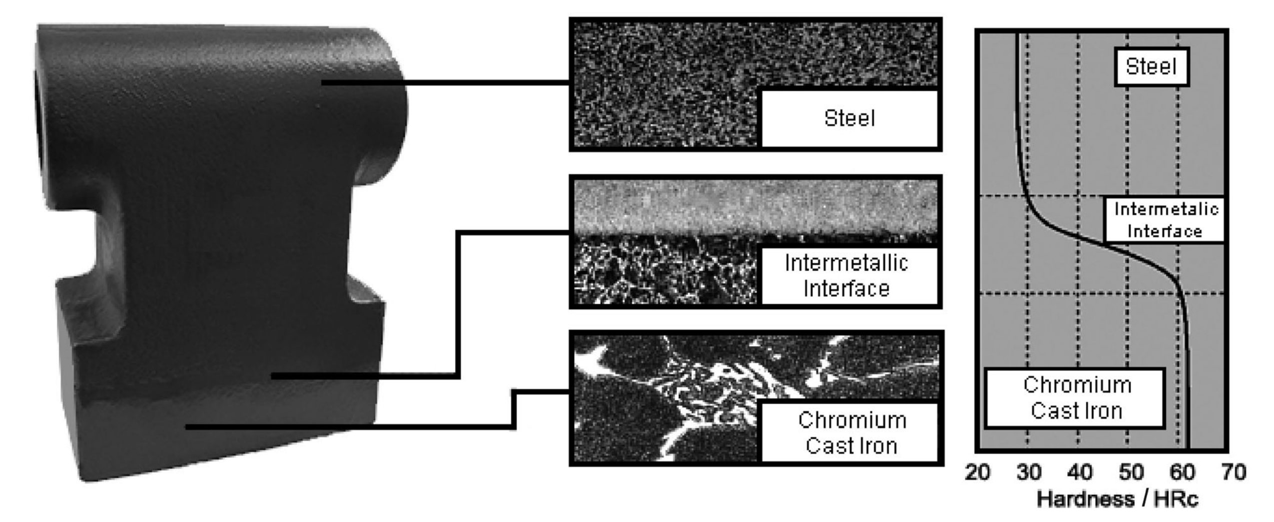

Figure 3. Metallurgy and hardness of bimetallic hammer castings [7]

Inspection showed that monometallic hammers resulted in a weight loss of 1.48kg while composite bimetallic hammers wore 0.62kg.

In this case, life time by using bimetallic over monometallic was improved by almost 140% [7].

Other applications where high macro hardness and high amount of chromium carbide of M_7C_3 type resulted with significantly prolonged life time can be seen on example of coal crushing equipment. Every type of coal has different amount of quartz sand in it. Coal's hardness is between 0,2 and 2,5 Mohs [8], and quartz is very hard with hardness of 7 Mohs. Performance of bimetallic hammers in coal crushing application showed that bimetallic hammers with wear resistant chromium cast iron resulted in 5.5 times longer wear life over hardfaced ones [9].

CONCLUSIONS

Bimetallic hammers are designed to extend the life of each hammer application, resulting in reduced overall costs, longer MTBF (Mean Time Between Failure) and reduced overall downtime. New technologies permit the production of bimetallic wear castings independent from the materials used and the geometry or weight of the components. Two different molten metals are poured into specially designed mould. Using different ferro-based materials for the shaft and the wear parts gives the components a highly specialized portfolio of properties.

A significant improvement in life span of parts which are subjected to high dynamical stresses and at the same time by high abrasive wear is possible

This enables significant reduction of costs due to repurchasing and changing of wear parts but also due to shutdown times.

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Note: Responsible translator: Elisa Velčić, Faculty of Engineering, Rijeka, Croatia