UPDATE OF THE DIAMOND TOOLS MARKET AND R&D ACTIVITIES IN ITALY

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Presented by:
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The diamond tools community in Italy

• In 2010 presentation two major points were highlighted;
  1) the plunge of the stone sector in Italy in 2009. In that year the total value of the italian export of natural stones (blocks, semi-finished and finished products) was 1,4 MM € (-24,5% over 2007)
  2) the positive outlook of the diamond wire-sawing, who was becoming a widely acceptred production technology
• Seven years after, the market situation shows “lights and shades”.
  The turnover of the stone sector continued to decrease
  The production of of multi-wires machines for the domestic and export markets grew by 20%
Global Trade Statistics for Stone Sector

• The global interchange of the stone sector in 2016 grew by 0.9% versus the previous year, accounting for a total volume of 53.5 million Tons. But this result has been achieved at the expenses of a reduction of 7% of the sales profits, with a consequent reduction of the global turnover in the excess of one and half million US $.

• The eight most important players on the worldwide scenario, which totalize a market share of 70% of the entire market, have shown a contradictory trend because four of them recorded a clear progress (India, Brazil, Greece and Turkey) while the remaining four have recorded a negative trend (China, Italy, Spain, Portugal).*

• Despite the negative trend in 2016 it must be highlighted that China remains the biggest exporter with a market share of 21.6%, followed by India with 18.4% and Turkey which has consolidated its third position with a market share of 12.4%.

• The Italian export of semi-finished and finished products in first half of 2016 grew by 0.6% and reached the value of 782.3 million di €. While the export of ornamental stones showed in first half of 2016 a reduction of 3.7%**

• The average cost per Ton grew, following a trend that started already in the previous years which tends to privilege the export of products with higher quality or otherwise with a higher cost.

• It must be highlighted that the average export price for the Italian finished products is 68 US$ per equivalent square meter (conventional thickness of 2 cm) and is almost two times higher than the world’s average.*

• The import of Italy is mainly represented by rough blocks and in the long terms this value has almost halved. At present has reached a value slightly above one million tons. (equivalent to the 6° place in the world)

* fonte MARMONEWS
** fonte ASSMARMOMACCHINE
Statistics Ornamental Stones - Italy

<table>
<thead>
<tr>
<th>Esportazioni prodottilapidei Gennaio-Aprile 2016</th>
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<td>EXP2015</td>
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- * fonte MARMONEWS
- ** fonte ASSMARMOMACCHINE
Italian Diamond Tools Industry

• Strong reduction of the production of circular blades (ceramic excluded) with consequent reduction of the domestic market
• The sector of diamond tools for the construction industry is facing difficulties to take off, and it does not represent more than 10 % of the total DT market.
• Segments for marble gang saw continue to be important, in particular for the export.
• Tools for calibration, polishing and finishing remains important (Vicenza and Treviso district)
• Multi-wire (about 10 manufacturers) among them one of the world’s leaders.
• Diamond wire is the product that is contributing more than others to the Italian DT industry
ITALIAN METAL POWDERS MARKET FOR DIAMOND TOOLS

Metal bond market for diamond tools 350 Tons/year
- Elemental mixing: 35%
- Cobalt: 25%
- Pre-alloys: 40%

Diamond tools market by application
- Construction: 10%
- Stones: 55%
- Glass & Ceramic: 35%
In 2016 export increased by 5.4%. Flat glass is driving the growth (+7.93%)*

The European Union remained the primary export destination for Italian glass processing machinery, accessories and special products, with 43% share of global market sales.

The sales outside the EU zone show a remarkable growth (+45%) for North America, with the US being the #1 customer, followed by Mexico.

China, who was ranking #46 in 2015 jumped to #4 in only one year. This demonstrates that the outstanding quality of the Italian machinery and equipment is appreciated by the Asian glass makers and the quality is recognized when top quality results needs to be achieved.

The growth of the export for Italian glass processing machines is “pulling” the production of diamond tools for the glass industry, since the high productivity and the quality of the finished product is depending to a large extent from the quality of the diamond tools.

* fonte GIMAV
Statistics Ceramic Industry - Italy

- In 2016 the domestic market grew by 5.5% equivalent to a total production 416 Million of sqm*
- Sales + 4.6% 341 million of sqmeters, equivalent to
- Export + 4.4%
- Production + 5.4%
- Porcellain gres is the most important product, accounting for more than 340 million of sqmeters, equivalent to 84% of the total production
- Also in the case of the ceramic market the growth of the export for Italian ceramic production is “pulling” the production of diamond tools for the ceramic industry, since the high productivity and the quality of the finished product is depending to a large extent from the quality of the diamond tools

* fonte Confindustria Ceramica
Italian multi-wire industry

- The production capacity of the Italian manufacturers of multi-wire is estimated between 1.6 – 2.0 x MM meter/year.
- Considering a selling price between 25 and 30 €/meter the turnover for the application is 50 to 60 x MM €/year.
- About 60% of the production is exported. (see map of the major countries)
- The progressive reduction of the beads’ diameter allows to increase the block yield by two slabs for 6,3 mm beads and 4 slabs with 5,3 mm beads. (for a block having 2,3 m width)
- Considering that each slab is 6 sqm, if the average cost per sqm is 100 US$ we have, for each block of granite an additional turnover of 1200 US$ for 6,3 mm beads or 2400 US$ for 5,3 mm beads.
- Considering 250 working days/year the increased block yield results in 300,000 € in the first case and 600,000 € in the second case. (almost the investment for the multi-wires machine)
Production of multi-wire machines

- The BRICS counties started to produce multi-wire machines locally. At the moment only 7,3 mm multi-wires machines are produced. The Italian MTB must maintain the leadership in the sector, introducing more advanced machines that can use wires thinner than 6,3 mm.
- Brazil: Espirito Santo, Bahia, Minas Gerais, Rio Grande do Sul – At present about 400 multi-wire machines are in operation
- Europe: Italy 50 machines; Spain 30 machines; Portugal 10 machines; rest of Europe 20 machines
- India: Rajasthan, Maharastra, Andhra Pradesh – At present about 40 multi-wire machines are in operation
- Asia: Taiwan 30 machines, China 5 machines, Vietnam 4 machines. This is the area where the high growth is expected in the next 5 years.
Pre alloyed bonds for free sintering

Since many years, for the production of diamond tools, cobalt has been widely replaced by pre-alloyed powders based on Fe-Co-Cu blends, produced by hydrometallurgical process. Some of these powders have proven to be particularly suitable for the utilization with the free sintering technology and their acceptance in the market is increasing year after year. These powders, constituted by elemental particles, each of them containing all the metals present in the alloy, having dimensions of 2-4 microns and high specific surface, and with high “sinterability factor”, represent an excellent base to start with the production of “proprietary bonds” by adding other metal powder in small or moderate quantity in order to modify the characteristics and the mechanical properties of the pre-alloyed base bonds commercially available.
Sr inkage properties of the pre-alloyed bonds

Not all the pre-alloyed bonds available in the market do have the characteristics required for the utilization with free sintering technology.

![Graph showing shrinkage rate under H2N2]

- Total shrinkage:
  - A: 4%
  - B: 6%
  - C: 12%
Free sintering of Cobalite CNF

Note:
Sintered density of Cobalite CNF is higher after 1 hr, but hardness is lower. This is probably due to grain growth at the longer sintering times.
Free sintering of Cobalite CNF mixtures

**Relative density of mixture 75% Cobalite CNF 25% Co EF**
Sintering time 1 hr

**Hardness of mixture 75% Cobalite CNF 25% Co EF**
Sintering time 1 hr
Cobalite CNF - Hardness (Rockwell B)
Mechanical properties of the pre-alloyed bonds

The addition to the base pre-alloyed powder of other metal powders can enhance the hardness and other mechanical properties like the abrasion resistance of the bond.
In the market have gained acceptance also mechanically pre-alloyed powders. Like chemically alloyed powders, these powders have been adapted and customized for free sintering technology. Like the chemically pre-alloyed powders, also these powders can be blended with other metal powders to modify their mechanical properties.
Self brazing bond

- The bonds based on pre-alloyed powders also do have very good self-brazing properties.
- The possibility to obtain a complete brazing layer between the bond and the steel support during the single step of the sintering process reduces the overall production cost of the free-sintered beads.
- The free sintering technology is still not very popular in the BRICS countries, where conventional sintering is still widely used. The production costs with hot press technology are supposed to be higher when compared to the free sintering technology.
Coated diamonds

The pre-alloyed powders do have also a good chemical affinity with the most common reactive coatings available in the market. The enhanced properties of the bond to retain the crystals allows the manufacturers to use a lower concentration of diamonds. The use of coated diamonds is well established in today’s production of diamond wires.
Research Activity at Universities

- The research in the last five years has focused on diamond wire
- The mechanical aspects, analysis of the cutting forces, vibration of the wire, correlation between cutting parameters and quality problems of the finished products.
- Resistance of the carrying wire as required by the decreasing diameter of the beads.
- Special Cutting Applications (Cast Iron, Underwater cutting)
- New sintering technologies
The free sintering technology is the favourite technology for the production of diamond beads because combines high productivity and low production costs.

The conventional hot pressing technology is still widely used for the production of segments, but there are new developments in enhanced, innovative, sintering processes.

Spark Plasma Sintering
ESF Electro Sinter Forging
Induction sintering

Perhaps the development of new hot press sintering machines can open new opportunities for the DT industry, in particular for high quality tools, which are still very important for the Italian industry of Diamond Tools.
INDUCTION HEATING in SINTERING

Presented by Dr. Franco Tagliabue
The heating of the powder (3) is generated through:

- the mould (1)
- the punch (2)
- graphite electrodes (4, 5)
- copper plate (6)
The heating of the powder (3) is generated through:

- the mould (1) 1 1
- the punch (2) 2
- Induction coil (4)

Inductive heating

1) Ring mould
2) Top / Bottom Punch
3) Powder Part
4) Induction coil
INDUCTION HEATING SINTERING

Inductive heating

1) Ring mould
2) Top / Bottom Punch
3) Powder Part
4) Induction coil

CONVENTIONAL HEATING SINTERING

Direct resistance heating

1) Ring mould
2) Top / Bottom Punch
3) Powder Part
4) Graphite electrode
5) Graphite electrode
6) Copper plate
INDUCTION HEATING SINTERING (I.H.S.) is based on Helmholtz induction coil.

The Helmholtz coil is a device for producing a region of uniform magnetic field.

It consists of two solenoid electromagnets on the same axis.
The two coils, with the same diameter and the same spiral numbers, placed at a specified distance, with the same axis, are serial connected to an alternating current generator, with the same direction of current.

The most simple geometry of two coils is their position at distance equal to the radius R and with the current in the same way.

The so obtained magnetic field is uniform in a wide area around the central point C, on coils axis.
The most important industrial applications are:

- the production of brake pads for motorcycles and cars;

- the production of diamond wheels, segments and tools, for:
  - mechanical industry
  - marble and granite industry
  - optic and glass industry
In induction sintering the heat is concentrated in the area where the metal powders are pressed, with the energy costs saving and the shorter heating cycles.

The coils, serial connected, are powered by a variable frequency generator, using different methods of heat propagation, as induction, convection, conduction and irradiation.

The temperature control is simple, uniform and constant;

It is possible to adjust in real time the parameters.

The temperature difference between the center and the external of the moulds does not exceed +/-5°C.
THE INDUCTION HEATING – 780 °C
THE INDUCTION HEATING IS:

ECOLOGICAL

- NO surface oxidation and the edge burning are reduced;
- NO smokes and NO noxious heat radiation;
- Very good environmental working conditions;

ACCURATE

- the temperature is uniform;
- the parameters are regulated with continuity;
- the results are reproducible;

LOW COST

- the maintenance and the installation costs are very low;
The table compares the conventional sintering and induction heating press. 1,600 moulds have been tested, with temperatures from 700°C to 950°C, surface from 100 cm² to 150 cm², mould height from 80 to 140 mm. With new I.H.S. the Energy Saving on the production is till 75% (at least), if compared to conventional system. Calculation base: 0,18 €/Kwh

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>€/KWh</th>
<th>KWh/mould</th>
<th>N. cycles</th>
<th>Cost</th>
<th>I.H.S. Saving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Sintering</td>
<td>0,18</td>
<td>15,00</td>
<td>1,600</td>
<td>4,320,00</td>
<td></td>
</tr>
<tr>
<td>Induction Heating Sintering (I.H.S.)</td>
<td>0,18</td>
<td>4,00</td>
<td>1,600</td>
<td>1,152,00</td>
<td>- 3,168,00</td>
</tr>
<tr>
<td>Standard sintering, Energy/year cost</td>
<td>0,18</td>
<td>15,00</td>
<td>19,200</td>
<td>51,840,00</td>
<td></td>
</tr>
<tr>
<td>I.H.S. Energy/year cost</td>
<td>0,18</td>
<td>4,00</td>
<td>19,200</td>
<td>13,824,00</td>
<td>- 38,016,00</td>
</tr>
</tbody>
</table>
INVESTMENT RETURN referred to ENERGY SAVING

AVERAGE COST OF I.H.P. : 200.000 €

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>YEARS</th>
<th>YEARS</th>
<th>YEARS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment Return</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Saving (€)</td>
<td>38.016,00</td>
<td>152.064,00</td>
<td>190.080,00</td>
</tr>
<tr>
<td>Standard Redemption (years)</td>
<td>10</td>
<td></td>
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</table>
## GENERAL COMPARATIVE TABLE

<table>
<thead>
<tr>
<th>TECHNICAL DATA</th>
<th>INDUCTION HEATING SINTERING</th>
<th>CONVENTIONAL SINTERING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sintering Surface</td>
<td>160 cm² (850°C 35 MPa)</td>
<td>160 cm² (850°C 35 MPa)</td>
</tr>
<tr>
<td>Power Supply</td>
<td>380 / 400 V 3 phs 50 Hz</td>
<td>380 / 400 V 3 phs 50 Hz</td>
</tr>
<tr>
<td>Total power</td>
<td>30 KVA</td>
<td>120 KVA</td>
</tr>
<tr>
<td>Nominal Current</td>
<td>3 x 37 A</td>
<td>3 x 210 A</td>
</tr>
<tr>
<td>Pressure Force</td>
<td>0 – 1.000 kN</td>
<td>40 – 950 kN</td>
</tr>
<tr>
<td>Max Opening</td>
<td>200 mm</td>
<td>200 mm</td>
</tr>
<tr>
<td>Inert Gas</td>
<td>15-25 l/min N2/Ar2 (max 5% H2)</td>
<td>15-25 l/min N2/Ar2 (max 5% H2)</td>
</tr>
<tr>
<td>Compressed air</td>
<td>2 l/min 6 bar</td>
<td>2 l/min 6 bar</td>
</tr>
<tr>
<td>Cooling water</td>
<td>5-10 l/min 2-3 bar 15-30°C</td>
<td>80-100 l/min 2-6 bar 10-25°C</td>
</tr>
<tr>
<td>Electrodes</td>
<td>Advanced Ceramics</td>
<td>Graphite</td>
</tr>
<tr>
<td>Controlled Atmosphere</td>
<td>Vacuum / inert gas</td>
<td>Vacuum / inert gas</td>
</tr>
<tr>
<td>Weight</td>
<td>2.500 kg</td>
<td>3.500 kg</td>
</tr>
</tbody>
</table>
I.H.S. - HOW TO OVERCOME LIMITS

The mass (mould and wheel) is heated in a completely uniform way. The cooling phase is longer in induction sintering, compared to conventional one, because the process needs more time to lower the temperature.

THREE OPTIONS HELP I.H.S.

1) Cooling station.
A cooling station, after the production press, reduces the dead times.

2) Automatic loading
The automatic loading allows the taking off the moulds from the press, at high temperatures, with the work safety and the press productivity.

3) Multi moulds
The heating distribution is very good. It’s possible to sinter more than one wheel, each cycle, with high quality results.
Steel moulds do not need special requirements, if compared to traditional sintering press, because the heat induction transmission is through convection, conductivity and irradiation
ENERGY COST TABLE – I.H.S. – WITHOUT COOLING STATION.

Calculation Base : 0.18 € /KWH
Working hypothesis : 230 working days, 10 hours / day,
I.H.S. without cooling station, 1 sintering cycle/ hour, 2300 cycles / year

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>€/KWh</th>
<th>KWh/mould</th>
<th>N. sinter. /year</th>
<th>Cost/year</th>
<th>Saving/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Sintering Energy cost / year</td>
<td>0.18</td>
<td>15</td>
<td>2.300</td>
<td>6.210,00</td>
<td></td>
</tr>
<tr>
<td>Elettron Induction Sintering Energy cost / year</td>
<td>0.18</td>
<td>4</td>
<td>2.300</td>
<td>1.656,00</td>
<td>- 4.554,00</td>
</tr>
</tbody>
</table>
ENERGY COST TABLE – I.H.S. – WITH COOLING STATION.
Calculation Base : 0,18 € /KWH
Working hypothesis : 230 working days, 10 hours / day,
I.H.S. with cooling station, 2 sintering cycles / hour, 4600 cycles / year
(*) with the cooling station, the energy cost / year is the same but the single
wheel cost is the half, because the production doubles.

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<tr>
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<td>6.210,00</td>
<td></td>
</tr>
<tr>
<td>Induction Sintering Energy cost / year</td>
<td>0,18</td>
<td>4</td>
<td>4.600 (*)</td>
<td>828,00</td>
<td>-5.382 (*)</td>
</tr>
</tbody>
</table>
Helmholtz method allows to distribute on the workpiece a constant temperature, while in the traditional systems, the heat transfer occurs by contact between the electrodes and the mold, without the guarantee that the temperature is perfectly distributed. The temperature distribution is optimal: the sintering is the wheel core.

Conduction, convection and irradiation, all together, contribute to get the best heating, with an 96% efficiency versus the conventional sintering with no more than the 50% efficiency.

I.H.S. – TOPICS

- temperature control with narrow tolerances (+/- 2°C)
- reliable sintering cycles
The I.H.S.
The coils, according to Helmholtz Method.
The I.H.S. at the end of sintering cycle.
The colour of the mould is uniform.
Thanks to

INDUCTION HEATING SINTERING

we can imagine a future:

- low cost energy
- more productivity
- more environment respect.

THANKS FOR YOUR KIND ATTENTION