STATE-OF-THE-ART SOLUTIONS FOR CUTTING AND GRINDING OF LARGE-SCALE STEEL AND SPECIAL ALLOY PRODUCTS*

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Abstract

At various stages during their manufacturing processes - from casting to finishing before delivery - semi-finished steel and special alloy products must be cut and surface-treated as well. The requirements for the individual conditioning steps, however, can be quite different. For example, the work piece can be hot, warm or cold. At any rate, the product must always be perfectly prepared for the next manufacturing step - reliably, in the shortest-possible time and at the lowest-possible cost. For cutting and grinding, BRAUN has developed innovative technologies and highly flexible, tailor-made solutions which meet these requirements in the most optimal way. In particular, BRAUN's cutting and grinding technologies can also be used for large-scale products.
Keywords: abrasive cutting, high-pressure grinding, product quality improvement, production process improvement

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1 INTRODUCTION

After BRAUN had developed the dry abrasive cutting technology in 1965 and had then built the first large-scale dry abrasive cut-off machine in 1969 (for cutting wheels with a starting diameter of 1.250 mm, at that time the largest wheels available on the market), abrasive cutting has become a widely used cutting process in the steel and special alloys industries. It is utilized for hot, warm and cold cutting of cast, forged, rolled products of different sizes and shapes, as well as for cold cutting for various upstream and downstream conditioning processes until the final cutting of the finished products.
Also high-pressure grinding has been a widely used surface conditioning process for many years. With the development of the first multi-functional HP (high-pressure/high-performance) grinding machine by BRAUN in 1999, however, high-pressure grinding was brought to an even better level of quality, performance, automation and reliability. Like abrasive cutting, HP grinding is used for the conditioning of different kinds of products.
In the following, the key design features and advantages of BRAUN's high-performance abrasive cut-off and HP grinding machines will be introduced. BRAUN's developments and machine designs to ensure that abrasive cutting and high-pressure grinding can cope with the trend that product sizes, cross sections and weights have been steadily increasing during the past 15 years (and continue to increase) will be explained as well.

2 FEATURES AND KEY ADVANTAGES OF ABRASIVE CUTTING

The tools used for abrasive cutting are the cutting wheels (see figure 1). These high-performance tools are produced in a multi-stage manufacturing process by specialized companies. The individual raw material components forming the wheels are the grain (regular aluminium oxide, special aluminium oxide or zirconium aluminium oxide), the bonding, and fibreglass fabric reinforcements. The actual composition of the cutting wheel depends on the specific application. Certain criteria such as material temperature, material shape and size, type and grade of material, play a dominant role.

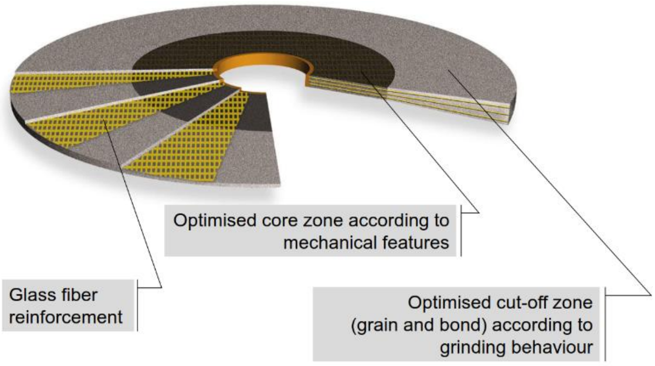

Figure 1. Basic Structure of a cutting Wheel (picture: Tyrolit)

Abrasive cutting has many advantages:

- Abrasive-cut bar ends are straight, precise and clean and can be reliably achieved thanks to the consistent self-sharpening of the cutting wheel (see figures 2 and 3)
- Suitable for an extremely wide range of materials, from unalloyed structural steels to high-alloyed, high-carbon steels, titanium and nickel alloys, as well as other special steels and non-ferrous alloys

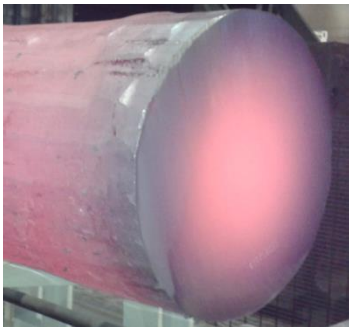

Figure 2. Cold cut product ends **Figure 3.** Hot cut product end

- Suitable for cutting hot, warm or cold materials. This is of special importance if the hot workpiece cannot be cut immediately after a hot forming process, such as during hot rolling or forging where the product cools down in the event of interruptions in the process flow.
- A high-performance stock removal process with short cutting times thanks to a high abrasion rate. Depending on the temperature and the size of the material to be cut, a well-designed machine can achieve specific cutting rates of up to abt. 50 cm²/s for hot cutting (from abt. 700 to abt. 1.150°C), up to abt. 35 cm²/s for warm cutting (from abt. 200 to abt. 700°C) and up to abt. 20 cm²/s for cold cutting (less than abt. 200°C) (see figure 4). In this context, the material grade plays only a minor role so that basically all materials can be cut equally well with maximum cutting speed.

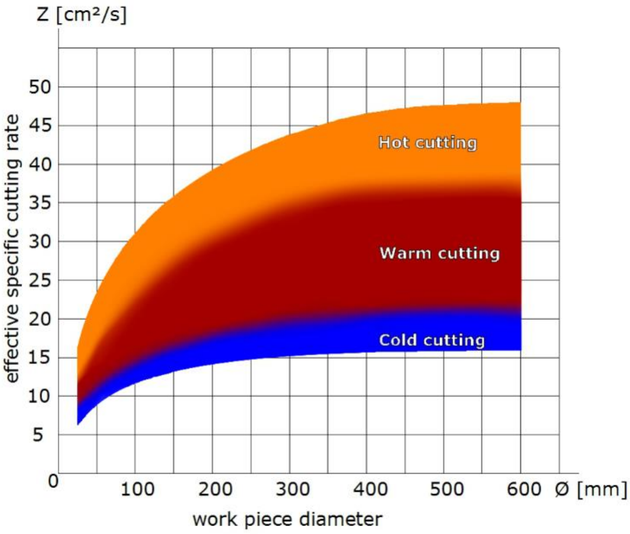

Figure 4. Specific cutting rates in relation to material temperature and workpiece dimension

- Thanks to its fully automated operation, an abrasive cut-off machine can perfectly match the operational requirements (particularly of continuous production processes). Specific cutting programs are stored in the abrasive cut-off machine's PLC which can be interfaced with the mill control system so that all necessary product data, as well as the cutting requirements can be automatically transferred to the PLC and the proper cutting program selected automatically.
- The application of liquid coolants during cutting is not necessary (dry process).

3 ABRASIVE CUTTING OF EXTRA-LARGE PRODUCTS: CHALLENGES AND SOLUTIONS

Traditionally, abrasive cutting has been mainly used for cutting of long products, such as e. g. in bar mills, after a radial forging machine or for conditioning of bar products (e. g. in conjunction with a straightening or a peeling line).
The following applications for abrasive cutting are relatively new ones:

- Traverse cutting of slabs, hot-rolled plates and sheets
- Cutting of large-size (round, squared or flat) forgings (also from open-die presses)
- Cutting of ESR or conventionally cast ingots

Only thanks to the development of extra-large machines and to special material handling equipment, as well as the availability of accordingly large cutting wheels from more than one wheel manufacturer, the abrasive cutting technology has become a viable solution for these applications.
Hot cutting of single bars right after a radial forging machine is mostly a chop-stroke cutting operation. Machine types TS xx W (with horizontal cutting rocker) and TS xx L (with linear-guided cutting head) from BRAUN are the most typical machine designs for these applications. Here the cutting wheel diameters were typically 1.250 mm or 1.600 mm but have recently reached 2.000 mm due to the increasingly large product sizes being forged (see figure 5).

Figure 5. BRAUN abrasive cut-off machine, type TS 20 L (2.000 mm cutting wheel dia.) for hot cutting of forged bars

For traverse cutting of wide slabs, flat forgings from an open-die press, as well as hot-rolled plates or sheets, it is recommended to move the horizontal cutting slide with the cutting wheel overhead on a rigid gantry structure (see figure 6). The first traverse abrasive cut-off machine of this kind (BRAUN machine type TS xx FP) went on stream in 2003.

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Figure 6. Gantry-type traverse abrasive cut-off machine, type TS 16 FP
(1 600 mm cutting wheel dia.) for hot cutting of up to 2 000 mm wide plates
and sheets, as well as cold cutting of slabs to shorter segments for cross rolling

When BRAUN designed and manufactured the first abrasive cutting facility for large-size ESR ingots in 1998, the largest available cutting wheel diameter was 1.600 mm and the two chop-stroke machines of type TS 16 W used for this cutting facility were designed for that wheel size.

Since ingots up to 915 mm diameter had to be cut, BRAUN developed and supplied a specifically designed material handling equipment including two special rotary chucks. By this means, ingots with diameters larger than abt. 450 mm could be cut in index cutting mode, i.e. the product is cut with three partial cuts whereby the workpiece is turned by 120° after the first and the second partial cut (see figure 7). This successful approach was also applied later-on for other applications where even larger products had to be cut.

Figure 7. Workpiece with 915 mm
diameter after index cutting

For the cutting of round ESR ingots and continuously cast slabs, BRAUN developed a combined gantry-type chop-stroke/traverse abrasive cut-off machine with specifically designed material handling gear. Roller tables allow a transfer of both the slabs and the ingots, whereby the round ingots with diameters up to 600 mm are automatically adjusted in their length direction by the center grooves in the otherwise cylindrical rollers.

For adjusting the up to 1.400 mm wide, 400 mm thick slabs, hydraulically actuated adjusting units are installed at both sides of the roller table and for turning ESR ingots with larger diameters, as required for index cutting, liftable turning devices are installed between some of the roller table rollers at both the inlet and the outlet side of the abrasive cut-off machine. These turning units can be lifted and lowered individually and accurately by means of hydraulic cylinders equipped with linear measuring systems so that they can also be used for compensating the tapering of the remelted/cast ingots.

By this means, the conical ingots are cut at a right angle (overview of this cutting facility with machine type TS 18 FP - for cutting wheels up to 1.800 mm dia. - see figure 8).

Figure 8. BRAUN gantry-type chop-stroke/traverse abrasive cut-off machine, type TS 18 FP, for cold cutting of tapered ESR ingots and continuously cast slabs

A similar but even more sophisticated approach was chosen by BRAUN for a cutting facility designed for the cutting of hot-pressed forgings with either round (max. 600 mm dia.), squared (up to 550 mm sq.) or flat (max. 1.600 mm wide x 400 mm thick) cross sections (see figure 9). The machine type is a TS 20 FPS, a combined gantry-type chop-stroke/traverse abrasive cut-off machine which allows utilizing cutting wheels with a starting diameter of max 2.000 mm.

The special feature of that abrasive cut-off machine is the possibility to retrofit a second cutting unit (on the opposite side of the existing first one) on the same gantry structure to enable the abrasive cut-off machine to also cut round forgings with diameters up to 850 mm and up to 800 mm large squared forgings later-on, if the need arises without the need to turn those products (instead of cutting in index cutting mode, those extra-large round and squared forgings would then be cut with one cutting unit from one side first and then subsequently with the second cutting unit from the other side).

A specifically designed material carriage with supporting rollers mounted on top and equipped with material clamping devices for fixing the workpieces during cutting is used for carrying, transferring and positioning of the forgings. Loading the hot forgings onto this carriage and removal of the cut pieces is done by means of heavy fork-lift truck – the usual way for transporting materials in that particular plant. The cut-off end pieces of the forged parts are collected in scrap boxes placed on cars attached at both ends of the material carriage.

Figure 9. Gantry-type abrasive cut-off machine of special design, type TS 20 FPS for hot cutting of round, squared and flat forgings coming from an open-die forging press

Apart from the development of abrasive cut-off machines for 1.600 mm, 1.800 mm or 2.000 mm cutting wheel diameters, with special design features and specific material handling systems, one important factor why such huge cutting facilities could have been installed and put into operation was the development and the availability of adequately large cutting wheels. Currently, 2.000 mm cutting wheels are available from three manufacturers, and a fourth can produce wheels up to 1 850 mm diameter. All four wheel manufacturers possess a world-wide sales and service network and are technology partners of BRAUN. Thus, such large-size cutting wheels can be obtained at competitive prices and with professional technological support.

4 FEATURES AND KEY ADVANTAGES OF HIGH-PRESSURE GRINDING

High-pressure grinding is the most reliable and most effective technology to achieve perfect, fault-free surfaces of workpieces manufactured by casting, by forging or by other primary production or transformation processes. Thanks to its reliability, high capacity and flexible applicability, but also due to its high environmental compatibility, it is superior to other techniques, such as e.g. scarfing but also milling.

Depending on the type, quantity and distribution of the surface flaws, either the entire surface or only certain areas of the workpiece must be ground. We distinguish between the following 2 basic applications for high-pressure grinding:

- Bright grinding of the entire surface
- Controlled grinding of partial surface flaws

Hot-pressed grinding wheels (see figure 10) are used as tools for the high-pressure grinding process. In order to meet the requirements of the respective grinding application (e.g. regarding surface roughness, grinding depth, brightness of the surface, etc.), it is necessary to select the proper wheel specification (i.e. type and size of the abrasive grains, etc.) according to these requirements.

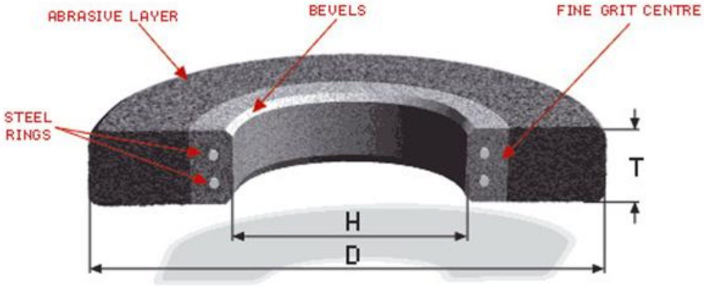

Figure 10. Basic Structure of a Hot-pressed Grinding Wheel

Apart from the selection of the proper grinding wheel specification, the design of the high-pressure grinding machine is essential for achieving the desired grinding result. One of the most important factors is the grinding pressure applied. The grinding pressure must be accurately adjustable and kept constant during the grinding process. A fast-reacting grinding pressure control is essential to maintain the set grinding pressure, in particular if the surface of the workpiece is uneven. An ideal surface finish after grinding is shown in figures 11 and 12.

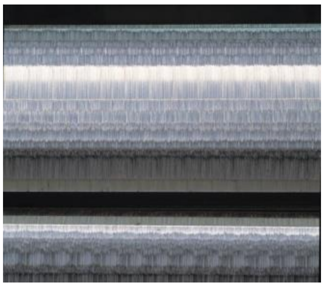

Figure 11. Ideal grinding finish (tool steel)

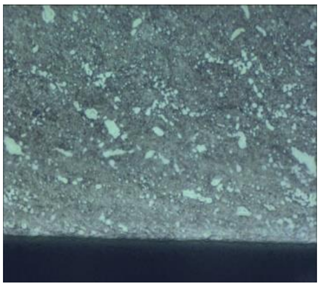

Figure 12. Decarburizing-free surface (tool steel - 1.500 : 1 magnification)

From the very beginning, during the planning and engineering phase of BRAUN's first HP grinding machine (in that case for grinding of continuously cast and rolled billets and suitable for the utilization of grinding wheels up to a starting diameter of 635 mm), BRAUN tried the utmost to not simply set up on known, conventional grinding concepts but utilizing the latest technical possibilities available at that time (1999) to develop a substantially improved machine design. Glancing back, it can be said that it was of great advantage that the first application posed some special requirements for the grinding unit (billets sometimes badly distorted, also very small billet cross sections to be ground - they tend to deflect during grinding -, huge variety of different materials - including many alloys sensitive to surface cracks and edge decarburization, etc.). Furthermore, it was beneficial that BRAUN took the operational experiences already made by the customer into account during the planning and engineering of the new facility.
Ultimately, the HP high-pressure grinding machine developed by BRAUN in this way represents a new, innovative grinding concept. This concept did meet the above-mentioned key criteria not only for the given billet grinding application at that time but also fully and perfectly for all other grinding machine projects executed by BRAUN later-on. Moreover, tailor-made facility concepts

were developed for each individual application, taking the individual, specific demands into account to the highest degree and to provide optimal technological solutions to the users of the facilities.

5 SPECIFIC DESIGNS FOR GRINDING OF LARGE-SCALE PRODUCTS

For the grinding of large-scale cast and forged products, some special criteria, such as e.g. the partly immense weight, as well as the actual shape of the workpieces need to be taken into account and determine the type of the grinding process and the design of the grinding machine.
After casting of stainless steel electrodes, it is necessary to remove the layer of slag or scale that sticks to the product surface. The removal of this layer is necessary to avoid impurities or defects inside the ESR ingots produced from the electrodes during a subsequent remelting process. Defects on the surface of the ESR ingots, such as e.g. cracks, need to be removed as well prior to subsequent downstream production processes like forging.
Round electrodes and ingots are usually ground helically, i.e. the workpieces, resting on turning units mounted onto the grinding carriage, are continuously rotated while the grinding carriage is moved slowly in longitudinal direction. To avoid a longitudinal displacement of the rotating products during grinding, the grinding carriage is equipped with specifically designed stop rollers as well.
Figure 13 shows a HP grinding machine, type HP 6 (max. 635 mm grinding wheel diameter) designed for the grinding of round stainless steel electrodes and ESR ingots with diameters ranging from 355 mm to 1.260 mm, lengths between 1.000 mm and 6.000 mm and weights up to 36 t.

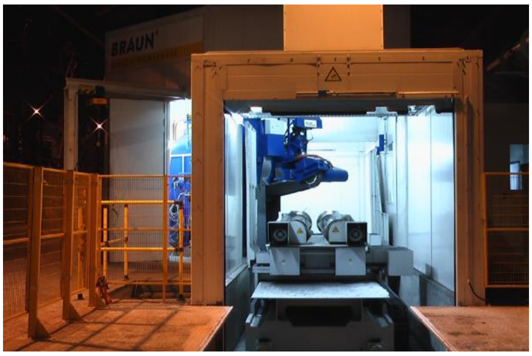

Figure 13. Grinding machine, type HP 6 for helical grinding of round electrodes and ingots

Another special feature of this particular HP grinding machine is a swarf collection system with 6 removeable swarf containers placed on a carousel. By this means, it is possible to collect the swarf resulting from the grinding process separately according to the specific alloys. Furthermore, not only the grinding unit but also the complete travel way of the grinding carriage is encapsulated with a sound-proof enclosure.
Large squared and flat products, such as ingots or slabs, are ground longitudinally. The workpieces are resting on the grinding carriage which is moved with high acceleration, sharp deceleration and maximum travel speeds up to 60 m/min (despite the heavy weight of the product to be ground).
After each pass, the grinding wheel is moved a certain distance (e.g. 20 mm) horizontally across the width of the workpiece. By this means, the entire product surface can be ground. The unique design of BRAUN's HP grinding machine allows a stepless adjustment of the grinding head between an angle of 90° and 45° (grinding axis = pivot axis of grinding head, thus allowing a re-adjustment of the grinding head even during the grinding process).
In figure 14, a grinding machine, type HP 6 built for the grinding of squared Titanium ingots (max. 850 mm x 850 mm) and of Titanium slabs (max. 1.100 mm wide, max. 300 mm thick) can be seen. Because the Titanium dusts are highly flammable and tend to explode, this particular HP

grinding machine is fully encapsulated and equipped with an explosion-proof dust extraction unit, as well as a flame supervision and fire extinguishing system. For an automated loading of the products onto the grinding carriage, for turning the product by 90° after completing the grinding of one side of the workpiece and for unloading, a charging and turning device is installed aside the grinding carriage.

Figure 14. Grinding machine, type HP 6, for Titanium ingots and slabs

For grinding of extra-wide and heavy steel slabs, BRAUN offers HP grinding machines equipped with 2 grinding units, a main (top surface) grinding unit for grinding the large top surface of the slab and - if required - an auxiliary (side surface) grinding unit for grinding the side surface of the slab. For the largest HP grinding machines, the main grinding unit is equipped with a pair of grinding wheels with 915 mm diameter and 125 mm width each and can be steplessly adjusted to any desired angle between 90° and 65°, whereas the auxiliary grinding unit is fixed at an angle of 90° and equipped with a max. 125 mm wide grinding wheel of max. 635 mm diameter. The horizontal slide of the main grinding unit is moved overhead, on a heavy-duty gantry structure across the entire width of the slab.
Figure 15 shows the layout of such large slab grinding facility with a grinding machine type HP 9-6 P and the entire material handling gear required for transporting, adjusting and turning the slabs.

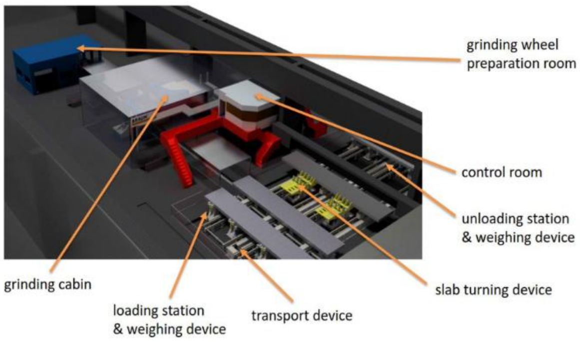

Figure 15. Overall layout of grinding machine, type HP 9-6 P, including material handling gear for grinding extra-wide slabs

Probably the most important special features of BRAUN's HP grinding machines are the sensitive, fast reacting grinding pressure control (this ensures a uniform material removal, a smooth grinding process and a perfect grinding result) and the high-performance grinding spindle with specifically designed gearbox. The oil lubrication system developed by BRAUN ensures a reliable and proper lubrication of all bearings and gears, as well as a permanent cooling by means of an oil recirculation and recooling system. By this means, a long service life of the entire grinding spindle can be achieved.
With BRAUN's multi-functional HP grinding machines for slabs, the following grinding programs can be performed:

- Skin grinding: bright grinding of the complete rolling (and – if desired – also side) surfaces of the slab
- Spot grinding: controlled grinding of partial surface flaws on the slab's rolling surfaces
- Pattern grinding: bright grinding of a pre-determined area of the rolling (and side) surfaces of the slab
- Longitudinal corner grinding: grinding of the long corners of the slab
- Traverse corner grinding: grinding of the corners at the face and tail ends of the slab

BRAUN's HP grinding machine design does basically allow to run all of these grinding programs automatically. For an automated spot grinding, it is possible to interface the PLC of the grinding machine with an automated surface inspection system or to download the coordinates of the detected surface flaws from a level 2 system into the grinding machine PLC.

6 CONCLUSION

In order to cope with the different challenges in preparing cast, remelted, forged, rolled and cold-conditioned steel and special alloy products for the next manufacturing steps or for the shipment to customers, the selection of the right process technology and of the proper machine design is essential. It becomes even imperative if the demands on product quality, production efficiency and process reliability are getting stricter and stricter and the workpiece dimensions larger and larger.
As far as cutting, grinding and deburring of various products is concerned, BRAUN's highly flexible, tailor-made and specifically designed solutions for abrasive cutting, high-pressure grinding and deburring grinding/chamfering meet the above-mentioned requirements to the highest-possible degree. With almost 55 years of experience in abrasive technologies for cutting and grinding, by focusing on ongoing research and development, as well as by maintaining a close collaboration with leading suppliers of cutting and grinding wheels, BRAUN possesses the necessary know how for planning, designing and manufacturing state-of-the-art high-performance abrasive cut-off machines, multi-functional HP grinding machines and highly flexible deburring grinding machines, along with customized material handling gears and automation systems for the customers' specific applications.

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