Pulp-stone design optimization for quality and production

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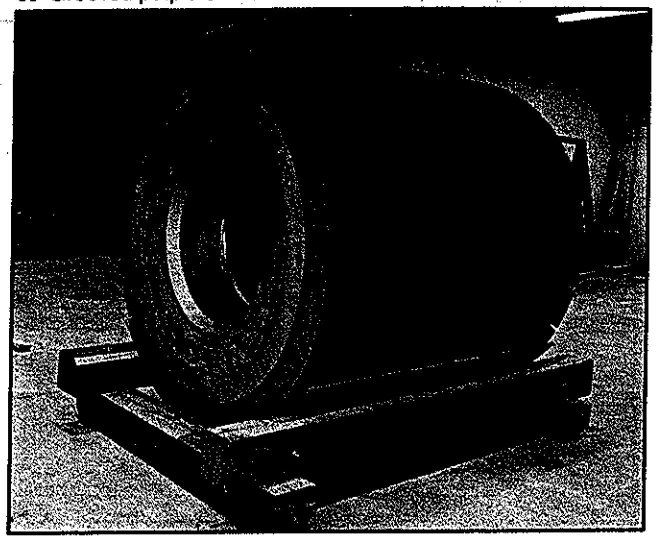
Computer-generated models were used to design a pulp stone equal to the demands of today's groundwood process.

The demand for groundwood pulp has increased in response to the trends toward lower basis weights and heightened requirements for printing properties in the sheet. Groundwood pulp has become a desirable component of paper machine furnish, especially for such publication grades as supercalendered, lightweight coated, and today's newsprint.

To meet this growing demand, producers worldwide are seeking maximum output from existing groundwood mills. In many instances, a variety of equipment and process improvements are being implemented to achieve that increased output.

As production is increased, there is often a coincident requirement for improved quality as well. In most cases, this creates a real challenge that involves production of a greater volume of lower-freeness pulp.

1. Grooved pulp stone



Background

A number of North American mills now have automated grinder-charging systems, which have measurably improved grinder efficiency in terms of both output and quality. Installation of control systems has also increased efficiency. In other cases, twin grinder sets have been converted to individual drives with increased power. Water-turbine-driven grinders have been changed to electric motors in still other cases.

There have also been radical new developments in the groundwood process itself. Most notable among these, of course, is pressurized grinding (PGW). As of this writing, approximately 67 PGW units are in operation or under construction, with several more in the study phase. Thermogrinding (TGW) is also growing in acceptance, especially in Europe. The Centri-Grinder is under development and also has attracted considerable interest in the industry.

Meanwhile, process developments continue to emerge in response to the growing demand for groundwood pulp. Grinder builders are offering a variety of modifications for existing equipment, such as improved finger-bar design and adjustment systems, among other features. Pulp-stone surface conditioning or sharpening has at last attracted designer attention. Not only are constant-speed, electrically driven sharpening lathes widely available now, but sophisticated, automated, and programmable sharpening devices have been developed and can be obtained. Showering in the grinders is being recognized as critical to the successful operation of the process, and a variety of improved shower pipe designs have become available to the industry. The PGW process is moving on to a second generation, with still higher operating temperatures and pressures. Heat recovery is available, and the addition of chemicals to the system is being carried out.

All of these process developments are aimed at raising pulp quality levels while simultaneously increasing production. Higher loading, elevated temperatures, and increasingly efficient grinder operation all add up to an intensified demand on the pulping medium, the pulp stone. The need for a better pulp stone was apparent, but it was also obvious that there was not a lot of readily accessible information that could be applied in an effort to improve pulp-stone design. Dynamic applications of reinforced-concrete bodies are quite rare. In fact, to date we have yet to discover another application.

In the early stages of this renewed interest in the groundwood process, a number of different ideas were

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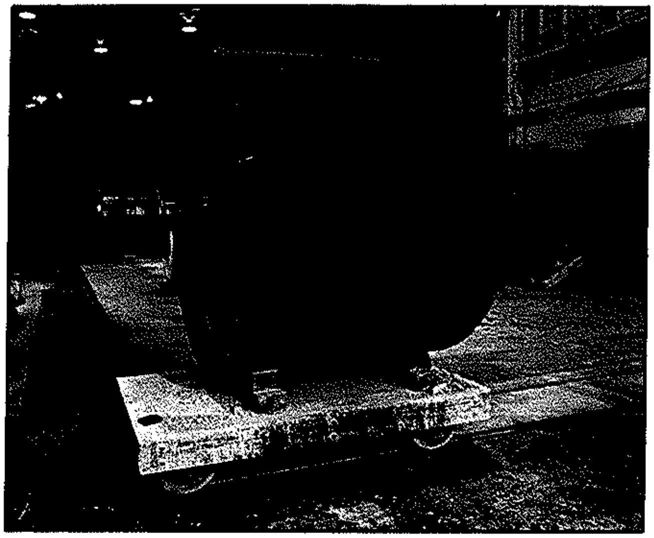
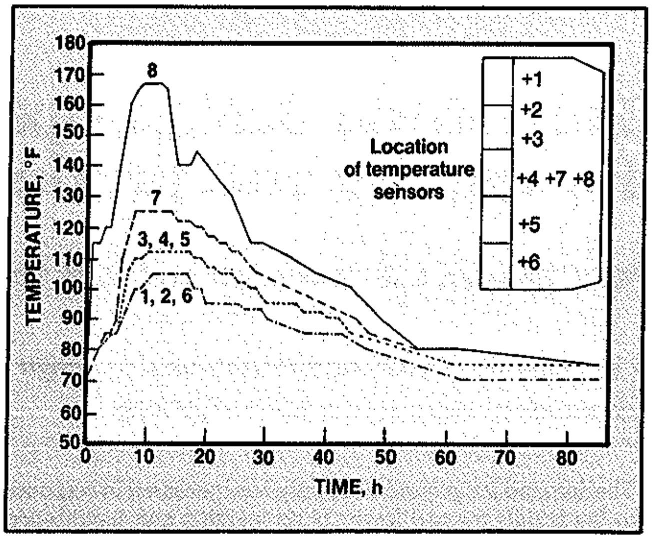
2. Pulp stone with Chevron grooves



3. Core temperatures over time at eight locations. Core locations are provided in the inset at the right



considered in attempts to improve pulp-stone performance and reliability. Some of these were even carried to full-scale mill trials. The grooved pulp stones in **Figs. 1 and 2** were among those tested.

The prevailing thinking in the case of these built-in surface configurations was that by dramatically increasing surface area, heat dissipation from the stone would be improved to a degree that would minimize thermally induced damage. At the same time, there was certain expectation that grooves would contribute to increased output from the stone by enhancing the compression and release action on the wood fibers.

Stud design—the method of fastening the abrasive segments to the core—was modified, and one radical departure in design was field tested. This involved a bolt through the segment to an internal anchor in the core.

Coincidentally, a grinder builder did extensive development work on a steel-core pulp stone with abrasive segments mechanically fastened, as opposed to the conventional method of casting the reinforced-concrete core inside the segment shell. Radically new abrasive materials were also used experimentally in conventionally constructed pulp stones.

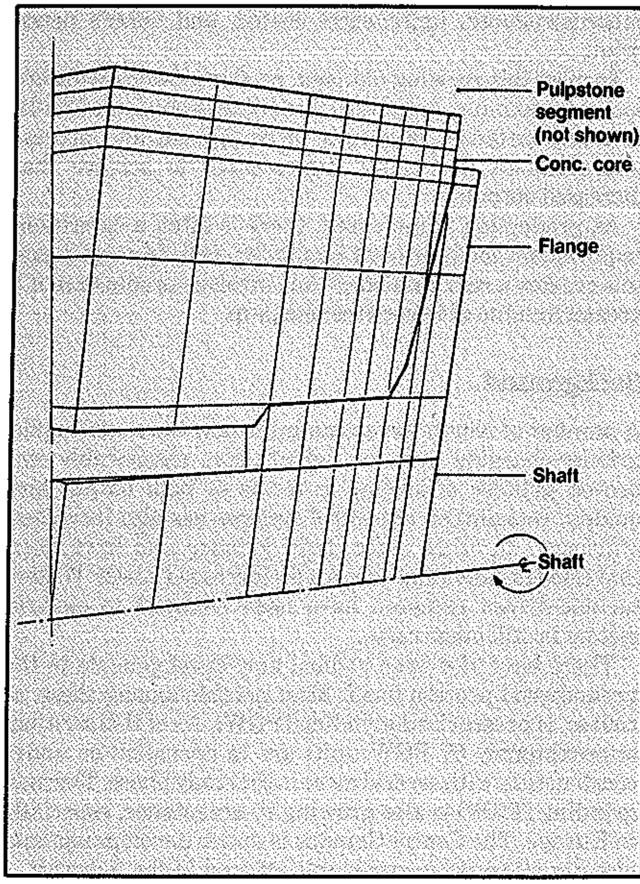
Most of these ideas were suspended after varying periods of operation, either for performance-related reasons or because of other constraints on continued development. However, there were enough encouraging results to assure continued follow-up in the future.

The "scattergun" approach to pulp-stone improvement was not going to produce the level of reliability required by the intensifying demands of the process. The pulp stone was running out of the over-design that is needed to withstand operating conditions that are not always perfect or on-the-mark.

When that fact was finally recognized, a decision was made to seek a systematic approach to the problem. An in-depth understanding of the compatibility of pulp-stone design to operating conditions was obviously a prerequisite to meaningful design modification.

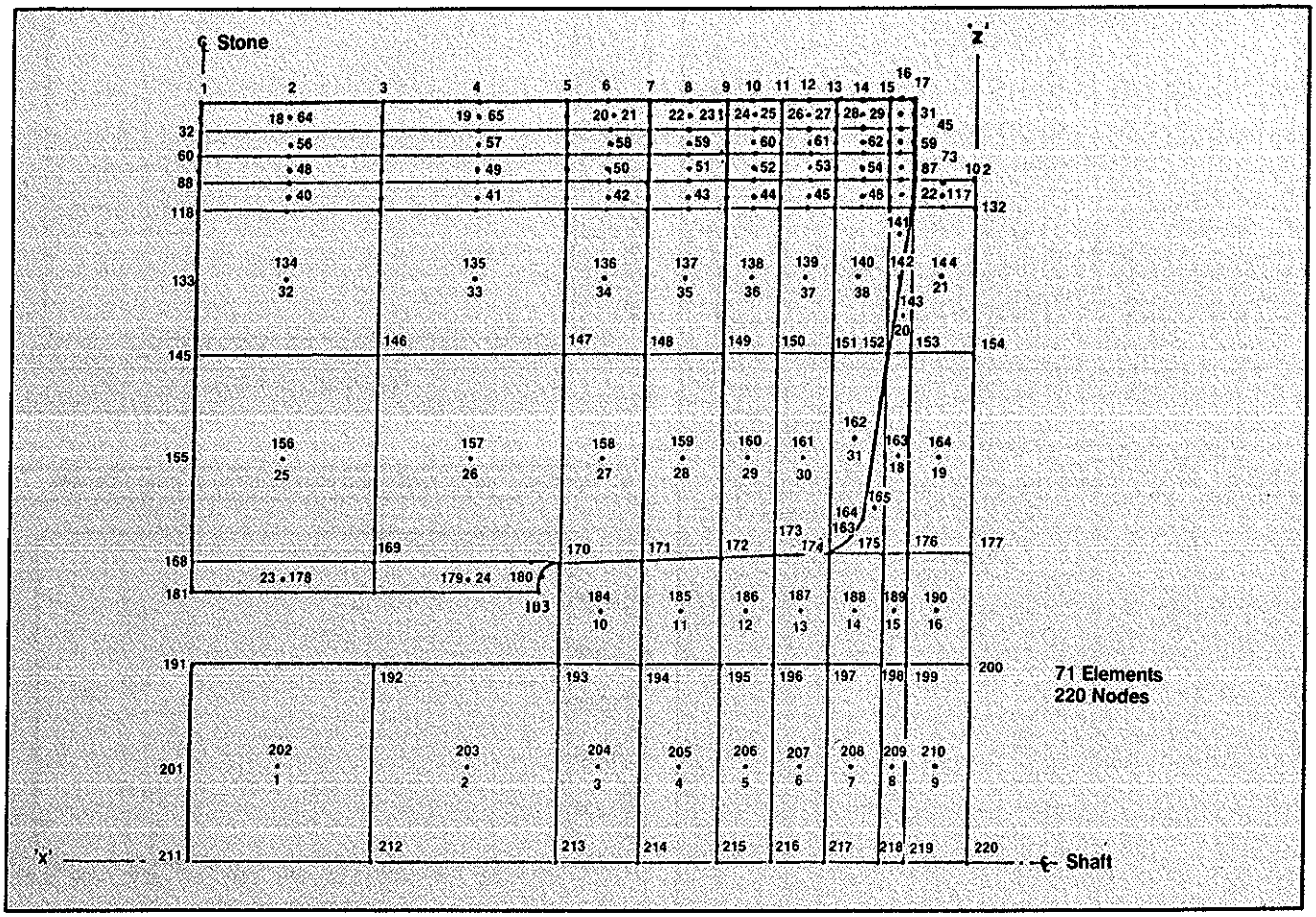
A study group was formed, and techniques for analysis were researched. The parameters to be studied were established as follows:

4. Axisymmetric model

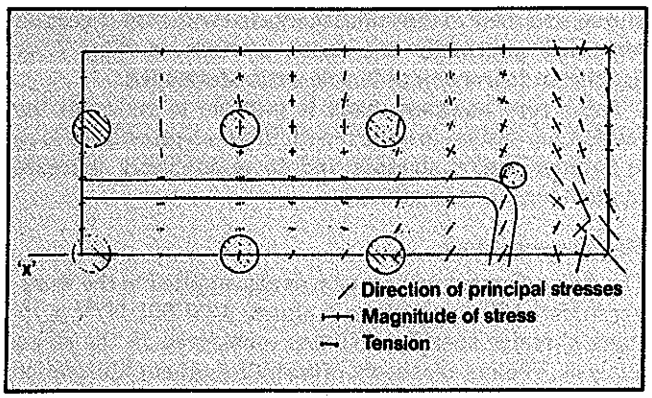


- Core materials: review each component and its interaction with other components to identify actual and potential problems.
- Core design: determine behavior of concrete and reinforcing materials under operational conditions.
- Abrasive segment: locate and calculate stresses in critical sections during operation.
- Studs or segment-to-core fastening system: evaluate the design and calculate stresses in operation.

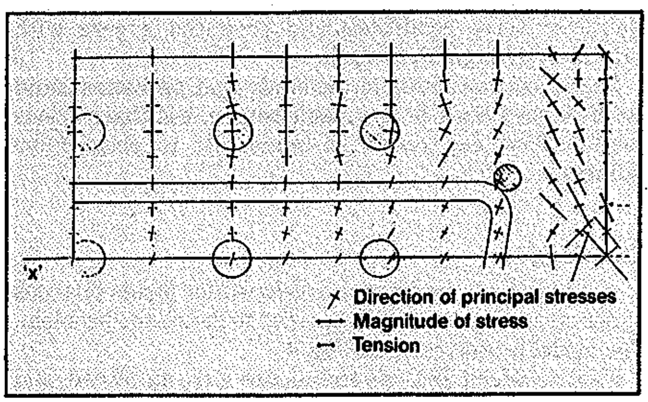
5. Finite-element model grid



6. Load case I included only the effect of flange clamping, centrifugal forces, and the effects of temperature. Principal stresses are located at the ends of the pulp stone and concentrated around the area of the outside diameter of the drive flange.



7. Load case II included the conditions of load case I, with the added condition of the compressive force of pocket load. The areas of stress concentration enlarged, and their magnitudes increased while the direction remained essentially the same. A significant increment of tensile stress developed.



- Manufacture: review the process and evaluate quality control and inspection procedures.

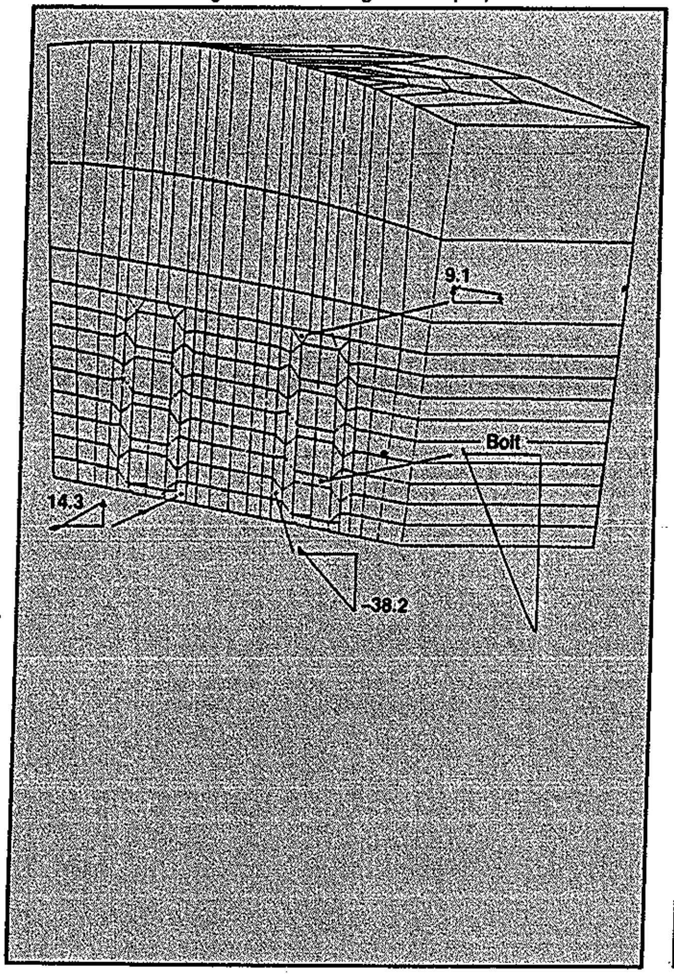
The study focused on the elimination of core cracking and segment pullout and the minimization of thermally induced segment breakage. Technology for the type of analysis sought was established.

The study

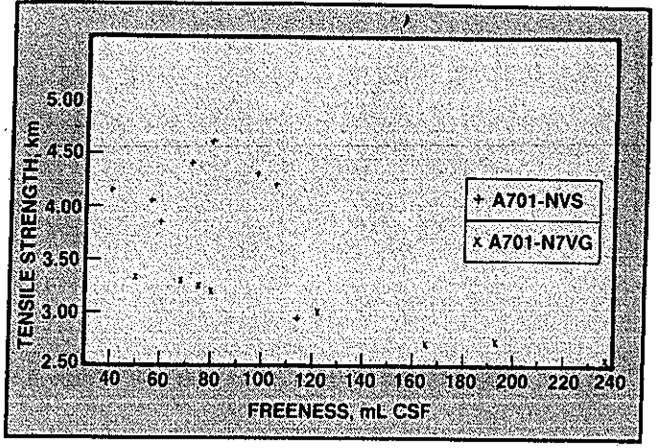
Core materials

For the first part of the study, thermocouples were placed in a stone prior to pouring of the concrete, and temperatures were monitored during cure. Location of the probes is provided in the inset on the right-hand side of **Fig. 3.** Each curve is plotted in degrees Fahrenheit against time in hours and corresponds to the temperature curve provided by one or more probes. Temperature differentials between

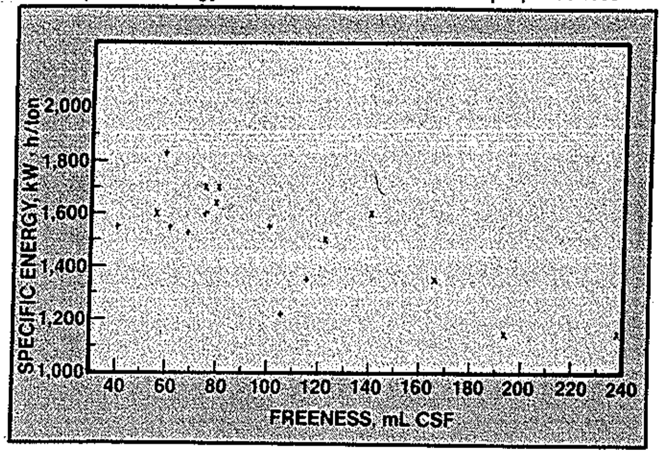
8. Finite-element grid of a half segment of pulp-stone surface



9. Tensile strength of paper as a function of pulp freeness



10. Specific energy consumed as a function of pulp freeness



probes were found to be excessive, which could be detrimental to the achievement of maximum strength in the core and, in turn, could contribute to failure. New concrete formulations and curing conditions were developed, which stabilized those conditions and produced a core with substantially higher strength.

There was consensus in the study that problems could not be traced back to any single source, but that various combinations can result in immediate to progressive failures.

Core design

A mathematical model was developed for stress analysis under operating conditions in order to define the problem. The model is illustrated in **Fig. 4.**

Finite-element analysis techniques were employed, and initial conclusions indicated that higher minimum-yield materials should be used in the redesigned core reinforcement. This was found to be significant to the core's ability to withstand continuous centrifugal loading, especially when no compressive pocket loads are applied, as when grinding. The elements were chosen, nodes located, and the grid was refined to the recognized critical area of the pulp-stone core. The finite-element model grid is illustrated in **Fig. 5.**

Two load cases were developed and subjected to computer evaluation. Load case I included only flange clamping and centrifugal forces, as well as the effects of temperature. Principal stresses were found to be located at the ends of the pulp stone and concentrated around the area of the outside diameter of the drive flange, as seen in **Fig. 6.**

In load case II, the compressive force of pocket load was added. The areas of stress concentration enlarged, of course, and their magnitudes increased while the direction remained essentially the same, as seen in **Fig. 7.** A significant increment of tensile stress developed.

These core analyses made it possible to redesign the reinforcing system in accord with finite-element lines so as to counter major stresses and to appreciably increase random tensile strength.

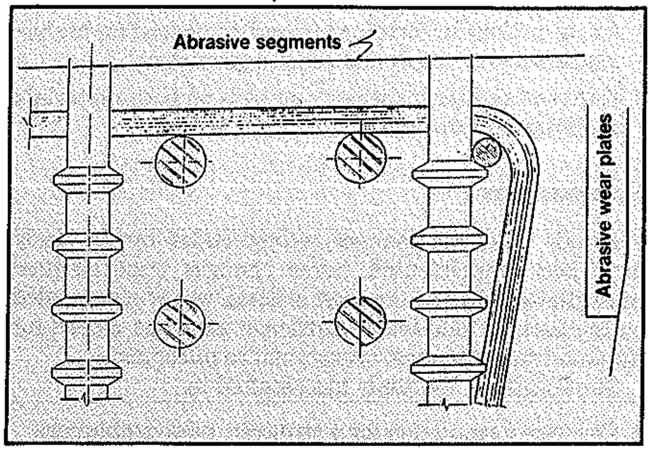
Abrasive segments

The finite-element technique was also applied to the working surface of the pulp stone. A classical 37C601-N7V pulpstone abrasive specification was considered in the stress analysis. Vectors are shown in the half-segment illustration of the pulp-stone surface in **Fig. 8.**

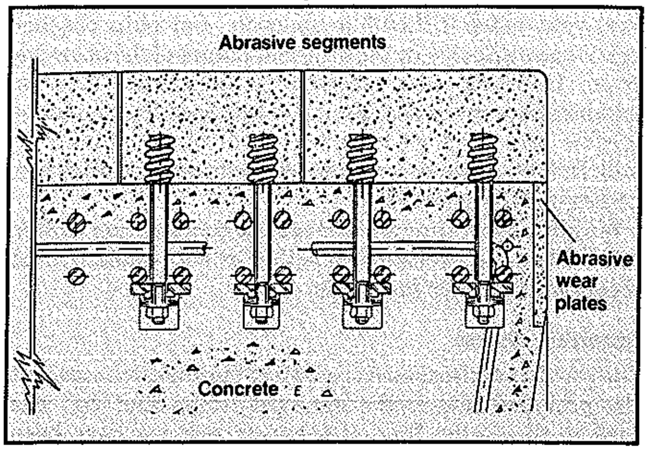
In the case of two-pocket hydraulic grinders, it was possible to calculate precise stress loads and identify critical locations by considering the cyclical stress loading of both segments and the fastening studs at two times per stone rotation. The largest tensile stresses in the segment were found to be mainly thermal stresses induced during operation. From additional laboratory testing of abrasive samples, a ratio of tensile to compressive strength was determined.

This phase of the study emphasized the critical importance of maintaining control of temperature differentials

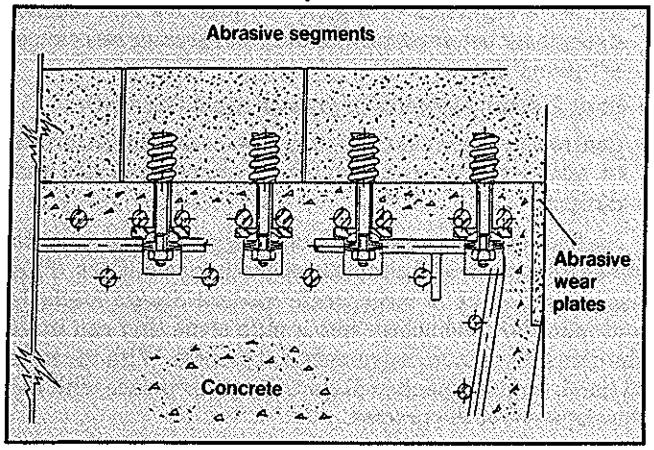
11. TR stud-attachment system



12. WRB1 stud-attachment system



13. WRB2 stud-attachment system



by providing adequate warm-up periods during startup and efficient cooling systems during operation.

Since inception of the vitrified bonded abrasive pulp stone, thermal shock has been recognized as the root cause for the most frequent type of damage to pulp stones in operation. The source of thermal shock is a subject too lengthy to be dealt with here. But our attention became focused on the importance of a higher-tensile-strength vitrified bonding material by (a) recognizing that thermal-shock failure (cracking, breakage) or spalling in a ceramic body is a tensile failure and (b) discovering during our studies that the largest tensile stresses in the segment are those induced by temperature differentials or thermal gradients that occur during the grinding operation.

At this point, it is essential to recognize that the increased strength being sought cannot simply be achieved by using more bond in the formulation of the ceramic body or, in this case, the pulp-stone segment. If that route were followed, obviously the pulp stone would be too "hard" for satisfactory operation. A suitable ceramic bonding material was found in development for conventional grinding-wheel applications and identified as "VS" bond.

We know that in ceramic bodies—pulp-stone segments are ceramic bodies—tensile strength maintains a ratio of about 10% of compressive strength. By way of illustration, the most commonly used type of vitrified bond in pulp-stone formulations has a compressive strength on the order of 92–116 MPa, while tensile strength runs 10-11.7 MPa. "VS" compressive and tensile strengths consistently run about 50% higher. Absolute figures vary with tests, but the relationship between the two materials remains quite constant.

The following results are from one set of tests where the new bond was tested against other conventional materials.

$$A601\text{-}NVS = 114\ N/mm^2$$

$$A601\text{-}N7VG = 70\ N/mm^2$$

By deduction, the increased tensile strength of the new bond should provide greater resistance to the stresses of thermal shock. That conclusion has been borne out by more than two years of experience in several demanding southern pine operations.

The higher compressive strength of this bond leads to better, stronger, longer-lasting patterns on the pulp stone. Of importance here is the fact that, although VS-bonded specifications are stronger, they are not harder and thus are not more difficult to sharpen. A pattern is produced with the same ease or difficulty as with conventional compositions.

It should be obvious that a longer-lasting pattern means longer sharpening cycles or fewer sharpenings. With fewer quality swings, overall pulp strength levels are higher and specific energy consumption is lower. Longer overall stone life is a logical conclusion.

The earliest VS-bonded pulp stones were run in Scandinavian mills, and their performance was tracked. The results for tensile strength as a function of pulp freeness are presented in **Fig. 9**. Results for specific energy consumed as a function of pulp freeness are presented in **Fig. 10**. The first of these pulp stones is still operating after more than four years in the grinder, with sharpening cycles more than three times longer than conventional stones in the same mill.

Another avenue toward a stronger vitrified segment was found in the use of high-purity, white, aluminum oxide abrasive ("38A") with the conventional bonding medium. The strengths and related results that were achieved were similar to those achieved using VS bond with regular aluminum oxide abrasive.

$$38A601\text{-}N7VG = 131\ N/mm^2$$

$$A701\text{-}NVS = 114\ N/mm^2$$

$$A601\text{-}N7VG = 70\ N/mm^2$$

Use of this abrasive has been limited until recently because the abrasive's crystal structure has made it somewhat more difficult to sharpen, and pulp characteristics are affected by the different nature of the abrasive grain. However, new sharpening devices on modern grinders have made sharpening of this specification manageable, and users are learning to control pulp quality as well. In fact, it has become the predominant specification for use in PGW operations.

Within a short time we will see the combination of 38A and VS bond in operation. Whether or not results will be synergistic remains to be seen.

Fastening system

The previously described analysis of the abrasive segment also provided data on the standard-design stud that was used in the study. Stud-attachment systems have been evolving through a series of designs from the basic TR type, as seen in **Figs. 11-13**.

As a result, it was recognized that a system with higher tensile strength was indicated in certain cases, and this modification was adopted.

Manufacturing process

The entire manufacturing process was reviewed in depth and in light of the findings of the various phases of the study. Some of the more significant developments include:

- Introduction of statistical process control (SPC)
- A procedure for evaluation of stud-to-segment strength
- Renovation of kiln controls for greater precision in the firing curves, thus assuring uniformity in the vitrified segments
- A new method for forming top-end-as-poured for higher compressive strength and precise geometry
- More and tighter inspection controls on both materials and stages in-process.

Conclusions

Virtually all of the changes recommended by the study have been implemented. Some changes were adopted immediately. Others, the most critical, were incorporated on the basis of field trials. Sufficient time has passed for implementation to meet operational requirements.

Summarizing, the study has resulted in:

- Concrete formulation for a stronger, more stable core
- Reinforcement designed to overcome the identified stresses in the core
- Abrasive segments of higher compressive and tensile strength for better pattern holding and greater resistance to thermal shock
- Stud fastening systems of greater tensile strength
- Controls in the manufacturing process and in materials to assure optimum utilization of new materials and designs.

State-of-the-art computer technology has been used to generate models and simulate operating conditions. This has permitted us to incorporate modern design methods and materials technology into a pulp stone that can meet the demands of today's groundwood process. With the tools at hand, improvements will continue to keep pace with the development of the process.

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