Research on Sawing Mining Technology of Soft Dimension Stone

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Abstract: China is the main production and consumption country of dimension stone in the world, the development of dimension stone industry is of great significance. According to the concept, types and characteristics of dimension stone, this paper analyzes the factors affecting dimension stone mining, introduces the general technological process of dimension stone mining. On the basis of analysis, comparison and comprehensive research, combined with literature and practical experience of dimension stone exploitation, the paper puts forward more advanced, efficient and safer soft dimension stone sawing technology and various concrete schemes of soft dimension stone mining, and also discusses the advantages and disadvantages of sawing methods and the future development trends of sawing technology.

1. The concept, types and characteristics of dimension stone

1.1. The concept of dimension stone
Dimension stone refers to a holistic stone material that can take advantage of its physical properties in a specific shape and size, such as marble finish, granite finish, square stone, strip stone, slate, mushroom stone, block stone, stone pillar, landscape stone, etc. It often uses the rock's hardness, strength, color, morphology, gloss and texture to form a specific shape, size of the whole to use. If it loses its overall character it will lose its value. China is the world's leading producer, exporter and consumer of dimension stone, which accounts for about 20% of the world's dimension stone production\textsuperscript{[1]}. Dimension stone has a strong decorative effect, buildings made of or decorated with it appear natural and quaint, durable, solemn and majestic. Ordinary building stone is the use of blasting or mechanical damage to the rock, and then broken into rubble, tiny rubble, stone powder and sand particles, reused as building materials.

1.2. Types of dimension stone
Dimension stone is generally divided into soft stone and hard stone. Soft stone refers to the relatively low hardness and strength, small-density, water-absorbing rocks. Its Moh's hardness is generally 3 to 5, Shore hardness is generally 40 to 60 degrees. It is generally sedimentary rock and metamorphic rock, such as limestone, travertine, sandstone, volcanic ashstone, fossil, marble, schist, slate, dolomite and...
serpentinite. Sedimentary rock and metamorphic rock deposits are mostly layered or similar, the ore body is large, the reserves are large. They are widely distributed on the surface of the earth's crust. According to the statistics, sedimentary rocks account for about 7.9% of the earth's crust volume, account for about 75% of the surface distribution, and metamorphic rocks account for about 27.4% of the earth's crust volume, account for about 18% of the surface distribution, but most sedimentary and metamorphic rocks can only be exploited and utilized as ordinary building stone materials. Soft dimension stone can only be those soft rocks with delicate and stable texture, few fissures, good overallity, beautiful color, beautiful patterns and bright color. Hard dimension stone refers to the high hardness, high strength, high density, no water-absorbing magmatic rocks, such as granite, gabbro, diorite, diabase and basalt. Its Moh's hardness is generally 6~7, Shore hardness is generally 80~100 degrees. Magmatites account for about 64.7% of the earth's crust volume, but only account for about 7% of surface distribution, and their ore bodies are mostly vein-type or blocky. Of course, this division is relative, for example, quartz rock is a metamorphic rock, but its Moh's hardness is 7, it is absolutely hard stone.

1.3. Features of dimension stone
Dimension stone is not only the use of its physical properties but also the use of its integrity, requiring stone beauty and integrity. Stone can generally be divided into Sedimentary, metamorphic, igneous and man-made rocks according to its cause. Generally speaking, soft stone has low hardness, low strength, loose structure, high water absorption rate, weak acid-base corrosion resistance, poor durability and weak weathering resistance. Soft stone is with a wide variety of colors, rich patterns, durability of about 100 years, low-cost, used very wide, often used as internal decorative materials. While hard stone has high hardness, high strength, dense structure, low water absorption rate, strong acid-base corrosion resistance, good durability, strong weathering resistance. Therefore, hard stone is often used as external decorative materials. It is much more difficult to mine and process than soft stone.

2. Major factors affecting stone mining

2.1. Geological and hydrogeological conditions
Rocks are formed under certain geological effects and geological environments, intrusive rocks and extrusive rocks are under magmatism, metamorphic rocks are formed under the effect of metamorphism, and sedimentary rocks are formed under the geological action of external forces. Because of their different causes, their mineral composition, structure, construction and properties vary greatly, the formation of rock shape and scale are different. In addition, their rock formation process and the after geological effects are different, resulting in different fissures. Those with too low hardness, lack of characteristics, subjected to severe geological action and poor rock integrity, generally can not be used as dimension stone, they can only be used as ordinary architectural stone to mine. Hydrogeology is also the impact factor of stone mining, especially in the use of deep-trough or well-type open-pit mining. Underground water impact is often very large, the problem of ground and underground drainage is needed to consider.

2.2. Terrain conditions
The terrain conditions in which the ore body is located have a profound influence on the way the stone is mined. When the ore body is located in the hillside area and its cover layer is thin, the hillside open-pit mining can be taken; when the ore body is located in the flat or low place and the cover layer is thin, depression open-pit mining can be used; when the ore body is located in the flat low area and the ore body extension is very deep, well-type open-pit mining can be used; when the ore body is located in the deep internal of mountain above the ground plane, tunnel mining can be used. Different mining methods mean different mining difficulties and mining cost. Open-pit mining on hillsides is the easiest and cheapest, and tunnel mining is the most difficult and expensive.
2.3. Burial conditions and occurrence of ore bodies
The depth of burial and extension of the ore body determine whether the ore body can be exploited and utilized. Those ore bodies buried too deep, covered too thick, or ore bodies whose surrounding rock is less stable may lose mining value due to mining difficulties. The direction, inclination, inclination angle and thickness of the ore body all affect the mining. According to geological survey report and reserve report, we can master the ore body occurrence and determine the ore body reserves in order to design the development and mining methods.

2.4. Lithology and quality of stone
The physical and mechanical properties of stone, especially hardness, strength, structure and construction, have a great influence on its mining methods. Magmatic rocks generally have a total crystalline isometry structure or variegated or plaque-like structure and have a block construction or flow construction. Metamorphic rocks generally have a crystalline structure or residual structure and have a block construction or sheet construction. Sedimentary rocks generally have a debris structure and crystalline structure and have layered construction or block construction. Therefore, we should consider the nature of the rock and choose the appropriate method. In addition, the quality and color of stone is very different, then its value is very different. Some kinds of stone are worth of only hundreds of yuan a cubic, some kinds of stone are worth of tens of thousands of yuan a cubic. For the high-value stone, sawing mining should be tried to use. For the low-value stone, artificial splitting, mechanical splitting and controlled blasting can be used to mine.

2.5. Geographical, transport and socio-economic conditions
Like ordinary mines, stone mines are restricted by geographical, transportation and local socio-economic conditions. Regional geography, traffic conditions and local socio-economic conditions should be fully taken into account. Geographical remoteness and backward traffic may seriously affect the development of stone mines. Social environment, market demand, product competitiveness and economic purchasing power not only affect stone mining, but also determine the survival of stone mines. Stone mines must be carefully planned and studied to make the right planning and decisions.

3. The mining process of dimension stone mines

3.1. Stone mining ways
Dimension stone mining is more demanding than ordinary stone and ore mining, not only to separate it from the parent rock, but also to maintain a certain shape, size and integrity, as far as possible without harming the rock or affecting the appearance. For example, do not form large fissures, burns and surface pollution. As mentioned above, there are many factors affecting dimension stone mining, which not only affect the mining ways and methods, but also restrict the cost and economic benefits of mining. At present, dimension stone mining is mainly open-pit mining, including hillside-type, depression-type and well-type mining, very few of which use tunnel underground mining. Where possible, open-pit mining should be preferred, which is with smaller development work, lower mining difficulties and lower cost. Only good quality, beautiful, high value stone ores, subjected to conditions, must use underground mining, will use underground mining methods.

3.2. The mining process of dimension stone
Dimension stone mines are generally open-pit mining, in accordance with the principle of open-pit mining, generally using top-down, layered mining. The general process of dimension stone mining is: in accordance with the mining design, after the completion of the mine infrastructure, in turn stripping the topsoil and weathering layer, making steps, opening up trench excavation, large separation, small separation, pushing and falling of small separation body, separation body lineation after overturned, separation body disintegration, rough stone block shaping, rough stone block
acceptance check, rough stone block movement, loading vehicle of rough stone block, slag clearance, the next stage of excavation\cite{2}. The entire mining process is constantly cycled in the new next phase. In the process of mining, we should pay attention to strictly control the final boundary of mine and final slope of mine.

4. Common mining techniques for soft dimension stone

4.1. Methods for the mining of soft dimension stone

Dimension stone mining has a long history and a variety of methods. China's stone mining methods in the past were relatively backward, generally using manual and mechanical splitting method, controlled blasting splitting method, static expansion agent splitting method, flame cutting method and wire rope sawing machine method, etc., which were of high labor intensity, low labor efficiency, low rough stone block rate, poor safety, heavy environmental pollution. With the development of technology and equipment, China's stone mining technology has developed rapidly, China has become the largest stone mining and processing country in the world. Mining methods are more advanced, such as diamond bead sawing, mining band sawing, chain-arm sawing, mining disc sawing and high-pressure flow water sawing\cite{3}. Wire rope sawing machine method has been phased out due to low efficiency, flame cutting method is only used in granite mines for mining trench excavation operations also due to higher cost. Compared with the splitting method, the sawing method is of higher degree of mechanization, lower labor intensity, higher labor efficiency, higher rough stone block rate, better safety, lighter environmental pollution and higher utilization rate of resources. It is the main method of soft dimension stone mining. Soft stone is low in hardness and low in wear-resistance, most kinds of soft stone have relatively poor splitting. They are more suitable for using sawing method. Especially with the development of diamond bead saws, mining belt saws, chain-arm saws and mining disc saws, they have more and more excellent mechanical performance, their manufacturing and maintenance cost is getting lower and lower, soft stone sawing method mining shows great advantages.

4.2. Comparison of various mining methods of soft dimension stone

To choose stone mining method, according to the actual and comprehensive comparison of the mine, we can find a more suitable mining method and specific scheme. Generally speaking, soft dimension stone preferred sawing method, while hard dimension stone preferred splitting method to mine. High-value dimension stone preferred sawing method, low-value dimension stone preferred splitting method. The comparison of various stone mining methods is as follows:

| method                        | artificial splitting | mechanical splitting | controlled blasting splitting | expansion agent splitting | diamond bead sawing | chain-arm sawing | mining disc sawing |
|------------------------------|----------------------|----------------------|-----------------------------|--------------------------|---------------------|-----------------|-------------------|
| adaptability                 | hard stone is better | hard stone is better | hard stone is better        | hard stone is better     | soft stone is better | soft stone      | soft stone is better |
| security                     | very poor            | poor                 | very poor                   | good                     | good                | good            | good              |
| resource utilization         | low                  | low                  | low                         | very high                | high                | high            | high              |
| productivity                 | low                  | high                 | high                        | low                      | high                | medium          | medium            |
| environment                  | poor                 | poor                 | poor                        | good                     | good                | good            | good              |
At present, there are many mining methods of dimension stone, but they all have their own limitations. A single mining method often cannot meet the needs of mining from both technical and economic aspects, so the above-mentioned mining methods can be combined to play their respective technical or economic advantages. Dimension stone can be mined by a single method, or by several methods of joint mining, depending on the mining conditions, surrounding rock conditions, ore body quality and scale.

5. Main sawing mining schemes of soft dimension stone

5.1. Full sawing mining with diamond bead saw
Diamond bead saws can mine both soft and hard stone. Through the deep large vertical and horizontal intersection holes which are drilled by rock drill, the side facade, horizontal bottom and back facade can be sawn by diamond bead saw. Diamond bead saw seam width is only about 11mm, soft stone cutting speed can reach 15 to 20m²/h, hard stone cutting speed can reach 5 to 10m²/h, sawing surface is flat and smooth, raw material is very regular. Diamond bead saw mining is extremely flexible, can be mined with high steps, medium and low steps, can also be used for separation, disintegrating or rough stone block shaping. The use of diamond bead saw mining requires a large number of auxiliary operations, such as drilling rope-through holes, the establishment of a variety of guide wheels, the establishment of cutting feeding columns and so on. Because diamond bead saws can be large-scale and high-power, so the separation can be very large, can be mined up to 56 meters high, which greatly improves mining efficiency.

5.2. Full sawing mining with arm saw machine
If the size of the ore body is very large, the length of the steps is more than 30 meters, you can first install the tracks, using a vertical arm saw machine for vertical sawing, using a horizontal arm saw machine for horizontal bottom sawing, you can complete the mining of low-medium steps, low width, large length separation body. The arm saw machine can be devided into diamond band saw and chain-arm saw. The diamond mining band saw is an improved model of chain-arm saw, its saw seam is about 38mm to 42mm, vertical cutting depth is up to 4.8m, horizontal cutting depth is up to 3.43m, can be used for closed face cutting without any help, soft stone cutting speed is up to 10 to 16m²/h. The saw seam of the mining chain-arm saw is also about 38 to 42mm, the mining chain-arm saw can even carry out dry cutting operations in mines lacking water resources, the current maximum vertical cutting depth of large chain-arm saws can reach 8m, the maximum horizontal cutting depth is up to 4.8m, its soft stone cutting speed is 10 to 15m²/h, slightly lower than the diamond band saw. The sawing surface is smooth and the rough stone block is very regular. Compared with the diamond bead saw, arm saw machine mining is more mechanized, less auxiliary work, but higher cost, can be used for high-grade marble mining.
5.3. Joint mining of diamond bead saw and arm saw machine
In order to give full play to the advantages of diamond bead saws and arm saws, joint mining method can be used. The use of arm saw machine for back facade cutting can reduce auxiliary work, the use of diamond bead saw for side facade or horizontal bottom cutting, this mining method can be used for low and medium step mining, step height is generally less than 8m. It is also possible to use arm saw machine for horizontal bottom cutting, diamond bead saw for side facade and back facade cutting, this can be used for high-step mining. In addition, the arm saw and diamond band saw can also be used for underground mining of soft stone. This mining scheme is more efficient and the cost of mining is significantly lower than that of full sawing of arm saw machine.

5.4. Joint mining of disc saw and diamond bead saw
Mining disc saw can not only mine soft stone, but also mine hard stone, can be parallel or orthographic arrangement of vertical cutting of the ore body, its saw seam is about 15 to 20mm, vertical cutting depth is up to 2m, it is now often used in granite mines in China. If the size of the ore body is evenly distributed, the mining work surface is large with the length of 40m and width of more than 20m, you can first install the tracks, use mining disc saw for vertical sawing, use diamond bead saw to cut horizontal bottom or disintegrate the separation body, this is the formation of joint mining of disc saw and diamond bead saw[5]. If the mining disc saw cross-cuts in accordance with the specifications of rough stone blocks, diamond bead saw for horizontal bottom cutting, we can directly mine rough stone blocks from the ore body. If the mining disc saw in accordance with the specifications of rough stone blocks for the same direction of back facade cutting and a certain distance of the side facade cutting, diamond bead saw for horizontal bottom cutting, can form a strip separation body, and then be disintegrated. This increases mining efficiency and reduces mining cost. This scheme is suitable for low step mining, which is generally less than 2 meters high. In addition, the mining disc saw can slice stone directly on site. China’s mining disc saw technology is advanced and of stable performance, disc saw equipment is extremely mature and has strong choice.

5.5. Joint mining of diamond disc saw and arm saw machine
Using mining disc saw to cut the vertical surface of the separation, arm saw machine to cut horizontal bottom surface, can form joint mining of diamond disc saw and arm saw machine[6]. If the mining disc saw cross-cuts in accordance with the specifications of the rough stone blocks, the arm saw machine cuts horizontal bottom, we can directly extract rough stone blocks from the ore body. Mining disc saw can also be in the same direction in accordance with the rough block specifications for parallel cutting of vertical back facade and a certain distance cutting of the side facade, arm saw machine cuts horizontal bottom surface, and then the segment separation is disintegrated into rough stone blocks.

6. Advantages and disadvantages of sawing mining method

6.1. Advantages of sawing mining method
Sawing mining is a high-tech and high-equipment level mining method, compared with artificial splitting, mechanical splitting, controlled blasting splitting and static expansion splitting, it has a high degree of mechanization, low labor intensity, operation safety, smooth cutting surface, narrow saw seams (diamond bead saw seam is only about 11mm, arm saw machine saw seam is about 40mm, mining disc saw seam is about 20mm, and splitting seam is more than 45mm and easy to produce new cracks), regular shaping, high rough stone block rate, high resource utilization rate, small environmental pollution. Sawing mining is the preferred method of soft stone mining.

6.2. Disadvantages of sawing mining method
Sawing method not only depends on the equipment and staff requirements, but also large mining investment, expensive equipment, high material consumption, high mining cost. Especially when mining hard stone, the mining efficiency of sawing method is low, but the mining cost is high, for
example, soft stone sawing by diamond bead saw is up to 15 to 20m²/h, while hard stone sawing by diamond bead saw is only 5 to 10m²/h. If the stone is low quality and low price, it may be difficult to bear its high mining cost.

6.3. Choice of sawing and splitting
The larger the size of the ore body, the more uniform the ore body, the higher the stone value, the wider the mining surface, the greater the mining depth is, the more advantageous the sawing method is. Therefore, according to the actual situation mining methods should be selected, and sawing method and splitting method also can be combined to carry out mining, in order to avoid their shortcomings, improve mining efficiency and reduce mining cost.

7. Future Trends of sawing mining techniques
Sawing mining method has broad prospects for development, the application of sawing mining is more and more extensive with the rapid development of science and technology today. The technology and equipment of sawing mining are more and more advanced. It has the following trends in the future:

(1) Sawing technology is becoming more and more advanced. Automatic control and automatic adjustment ability of diamond bead saw, arm saw machine and disc saw continue to improve accompanying with sawing material improvement and wear decrease, more and more safe and simple operation, more and more adaptable to various rock properties, more and more high production efficiency.

(2) Sawing mining equipment is becoming more and more advanced and complete. A variety of models become a large range of options. In particular, the use of self-propelled mining equipment with good mobility will improve the operational efficiency of mining, reduce the labor intensity of mine operators, and also improve the quality of mining work. Equipment performance continues to improve, wear durability is improved, prices of equipment and accessories are falling, material consumption is decreasing, mining cost is getting lower and lower.

(3) Joint mining has become a mainstream method of exploitation. A single mining method always has its limitations, with new materials and new technology application, the use of more than two mining methods, which complement each other and play their respective advantages, is more suitable for complex and changeable stone mines. In addition to the joint mining of various sawing methods, joint mining of sawing methods and splitting methods can also be used, especially in the mining of hard stone.

(4) New sawing methods will be applied. At present, high-pressure flow water cutting mining technology is being tested and in trial stage, its granite cutting efficiency is generally 1 to 1.5m²/h, sometimes reaches 2.4m²/h, sandstone cutting efficiency is up to 6.5m²/h. With the improvement of technical equipment, it is likely to become an efficient and safe mining method of dimension stone in the future. The development of high-energy laser technology may also produce advanced dimension stone cutting technology and equipment.

8. Conclusion
The development of dimension stone industry is of great significance. Considering the characteristics of soft stone and factors affecting mining, proper mining process and mining methods should be chosen. Sawing method is the best way to exploit soft stone. According to the actual situation, different sawing mining schemes of soft dimension stone can be used, and the sawing method and splitting method also can be combined to carry out mining in order to avoid their shortcomings, improve mining efficiency and reduce mining cost.

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