

AN OVERVIEW OF STONE AND MARBLE INDUSTRY OF RAJASTHAN WITH LIFE CYCLE ANALYSIS AND INDUSTRIAL SURVEY

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Date Received:

Date Revised:

Date Accepted:

ABSTRACT

This paper focuses on the economics, environment, technologies and issues experienced by marble industry present in the North western part of India taking Rajasthan as a case study. It classifies various marble deposits located in the surrounding area of Rajasthan with their traditional names. Rajasthan, which is considered as one of the significant state for production of stone and marble, disposes large quantity of marble waste, which is causing a severe destruction to the environment. To make effective use of this disposed waste a complete study on life cycle assessment according to ISO 14040/44 has to be followed for extraction process of marble stone in order to find some opportunities and potentials for waste minimization. A survey was conducted in different industries to find the types of tools used while machining. A number of local made inserts/segments were collected and characterized. For sawing different stone and marbles (of different hardness number) what are the proper compositions of the inserts/segments that should be used has been suggested. At last energy audit was conducted in industries to improve find out the power consumption, the slurry generated while cutting marble blocks are disposed in two different ways is demonstrated with different graphs.

Keywords: Natural Stone, Quarrying, Cutting, Machining, Environment Sustainability Index, Energy audit.

INTRODUCTION

Marble Industry of India is one of the ancient decorative and building material, which has an old history from 3200 BC. These dimensional stones have left deep imprints in the modern buildings of country. A number of temples, forts, and places of ancient Indian history have been engraved locally. These marble artifacts has even added to the current modern structures like the Government Executive houses, Legislative members' homes, Supreme and High Courts are made from a sandstone and marble. The growing eminence of Indian marble has accelerated the demand for its quarrying, due to its demand it has a great market not only in India but also from other countries like USA, Germany, France etc. Improper waste management strategies by stone and marble companies and the waste being dumped on land has caused a severe threat to the environment. Observing the significance of the condition, and supported by some local (Non-government Organisation) and other environmental administrations, the

Supreme Court ordered a complete ban on marble mining. The reporting of the problem by the mass media has upraised a source of anxiety for the Government of Rajasthan. The centre has set up a state-of-art R&D centre and stone testing laboratory to tackle the above-mentioned issues related to stones.

"The term marble is from Greek word Marmorous meaning shining stone". It is known for its great and variety of colours, smooth and uniform textures and rigidity. Marble is the most preferred stone in India. The marble deposits are existing in many states of India.

Andhra Pradesh and also in Madhya Pradesh as per the reports of Indian bureau of mines. Out of all the states Rajasthan has the most popular high graded marble stones. The important regions where marble deposits are present are given below (Prajwal, Mali, & Nagar, 2016).

- Udaipur-Rajsamand-Chittorgarh region.
- Makarana-kishangarh region.

- Banswara-Dungarpur region.
- Andhi (Jaipur)- Jhiri (Alwar) region and.
- Jaisalmer region.

The Figure 1 shows the various deposits of marble in the state of Rajasthan as marked •'

Various classifications of stones with their traditional names are listed in Table 1 which are distributed in different states of India (Prajwal, Mali, & Nagar, 2016).

Marble industry of Rajasthan is currently employing over 1 million people (Mali, Prajwal, Gupta, & Kishan, 2018). The different marble deposits present in different regions of Rajasthan is listed in Table 2.

1 . Economics of Stone Production

India is a major contributor in the global stone industry and provides huge revenue to the government. Figure 2 also reveals that India is third major supplier of stone and marble internationally. About twenty-seven percent of the natural-

stone products (Gunasekaran & Manicandan, 2009) in the international market are from India.

Out of this twenty-seven percent Rajasthan state alone accounts for about 10 percent (Gunasekaran & Manicandan, 2009). In Rajasthan, around 152,780 Hectors of land are reported to be under active mining.

States	Districts of State Where Marble Resources Available
Gujarat	Banaskantha, Bharuch, Vadodara, Kachchh and panchmahal
Haryana	Mahendragarh, Antri-beharipur, Zainpur, chappra,-bibipur, Nagaldurgu,
Madhya-Pradesh	Islampur, Dhanota-dhancholi
Maharashtra	Katta-Hiwara, Kadbikhera, Sakaritola, Pauni, Chorbaoili, Deolapur,
Uttarakhand	Mansar, Kandri, Chargaon, Junewali
Uttar Pradesh	Pithorgarh
Jharkhand	In Mirzapur at Hingha and geria
Andhra-Pradesh	Semra-salatua
	Khammam, Cuddapah, Kurnool and Anantapur

Table 1. Stones Available in Different Districts of States



Figure 1. Marble Deposits in Rajasthan Marked as •' (Prajwal, Sambharia, Mali, & Nagar, 2018)

Rajasthan Region's	Colour of Marble
Makarana	Pure crystalline marble, Alberta, Adanga, Dongri pink
Rajsamand	Off-white and greyish-white
Rikhabdeo-Kesariji	Green marble
Babarmal	Pink marble (fine graded hard marble)
Bhilwara	White to off-white, fine to medium graded hard marble having black and white
Banswara	White to off-white dolomitic marble and is soft
Jaipur	Greyish-white sold on trade name Andhipista

Table 2. Rajasthan Region Wise Stones and its Different Varieties

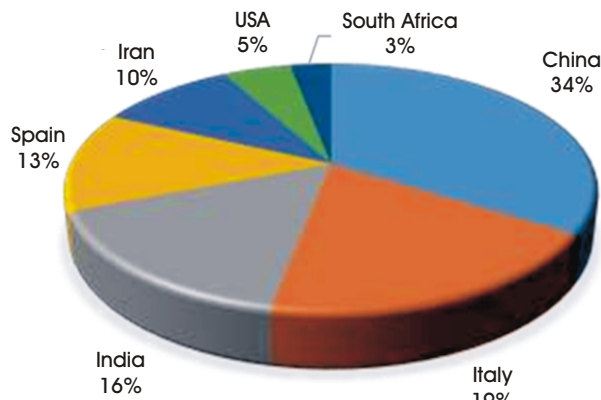


Figure 2. Production of Stone Worldwide

Rajasthan is well known as mineral majestic state of North India because it produces 50 varieties of mineral rocks. The state has huge deposits of natural rocks known as stones in local terms and a few important ones among them are granite, marble, sand- stone, Limestone, slate and quartzite. The stone industry not only provides opportunities, but facilitates occupation to a great number of people by igniting the poetic expression into the citizenry of this country, which is so vividly conveyed in several colours and sculptures in various stone built monuments of the country. A huge demand of the raw materials by the construction industry as building materials has increased the extraction of the marbles in recent years.

The increased popularity of marble stones in Rajasthan and high demand for polished and unpolished products, discovery of new marble deposits and growing demand for individual and public houses have resulted in significant development of marble industry in the country. Because of this demand, the number of marble, quarries as well as marble processing units have significantly gone up mainly during last two decades. Due to this rise in demand of finished and unfinished marble products, there is a

concurrent rise in the waste generation, thereby causing concern towards worsening in the environmental quality.

2. Environmental Challenges

Being a third largest producer of the marble in the world approximately 85% of India's production is received from Rajasthan. Rajasthan alone has 4000 marble mines and about 1100 marble processing plants. Due to these processes stone slurry generated corresponds to about 40% as final product. In recent times agreeing to the article of times of India (NOV 19, 2012) it has alleged that "There are 250 marble processing units in the industrial field and they are dumping about 70 tons of slurry daily as a result of which about 700x500 meters of the valley has been ruined" this dumped slurry is posing a menace to the valley (Rajgor & Pitroda, 2013) .The following are some of the listed hazards.

- Dumping of waste has reduced the prosperity of the land, water absorption and water percolation leading to poor land quality.
- Stone slurry which is carried out to the rivers, road drains, wells, bore wells and other water bodies are effecting the quality of the water. So, ultimately it is damaging the aquatic life.
- When the slurry becomes dry, the fine particles are quickly dispersed and it leads to air pollution.
- Most of the people's living in Rajasthan is through agriculture, due to the dispersion of this dry slurry in to air and water it started to effect the vegetation and plantation.
- Grown trees and bushes have died out (Prajwal, Chauhan, Mali, & Nagar, 2016). Animals have also been deprived of their food and shelter.
- There are a number of accidents due to improper dumping of waste on roads and on quarry sites.

Figure 3 shows the percentage of waste generated at each stage of the process.

The very fact of marble being dimensional stone, has contributed environment pollution due to waste generated at each stage of mining and processing operations (Mali et al., 2018).

Following two types of marble waste generated in the

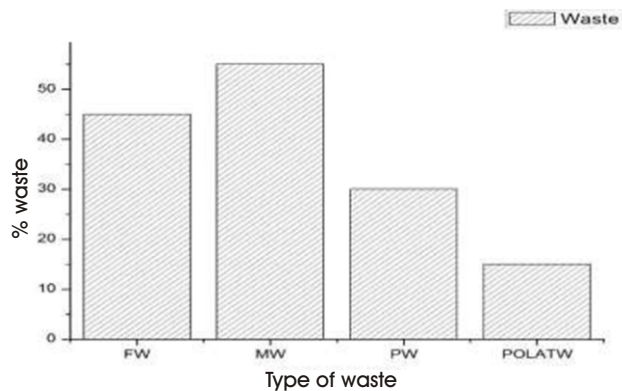


Figure 3. Various Percentage of Waste Generated in Different Sectors

region:

1. Quarrying waste
2. Processing Waste

Various percentage of waste that is generated by different mechanism like in Quarrying is shown in Figure 4, and percentage of waste generated while processing and polishing is shown in Figure 5.

3. Extraction Process of Marble

To find chances and possibilities for development of this industry, it is significant to study life cycle analysis of marble

extraction beginning from rock to construction (Figure 6). This flowchart of lifecycle of marble industry (Traverso, Rizzo, & Finkbeiner, 2010) beginning from quarrying stage where huge blocks of marble stones are cut using mechanized or non-mechanized techniques. These cut marble are then cut to suit various requirements in building industries to be used for different applications. A flow chart is designed for an easy understanding of extraction process.

Marble extraction starts from quarry, where rocks are pulled out from Rocky Mountains. This pulled out rocks are fed to the construction industries through different stages. At first extracted rocks are carried to cutting (factories and workshops) to be cut and turned into required dimensions to suit construction and building requests. At Second stage, these rocks from cutting shops are sent to polishing processing units where required improving is done. At final stage the remaining small pieces of stones are transported to crushers where they are further crushed into aggregates of various sizes, to be used as raw material in concrete mixtures. Dried stone powder from polishing and processings units can be utilized at construction site. The waste that is left out from buildings are re-sized and

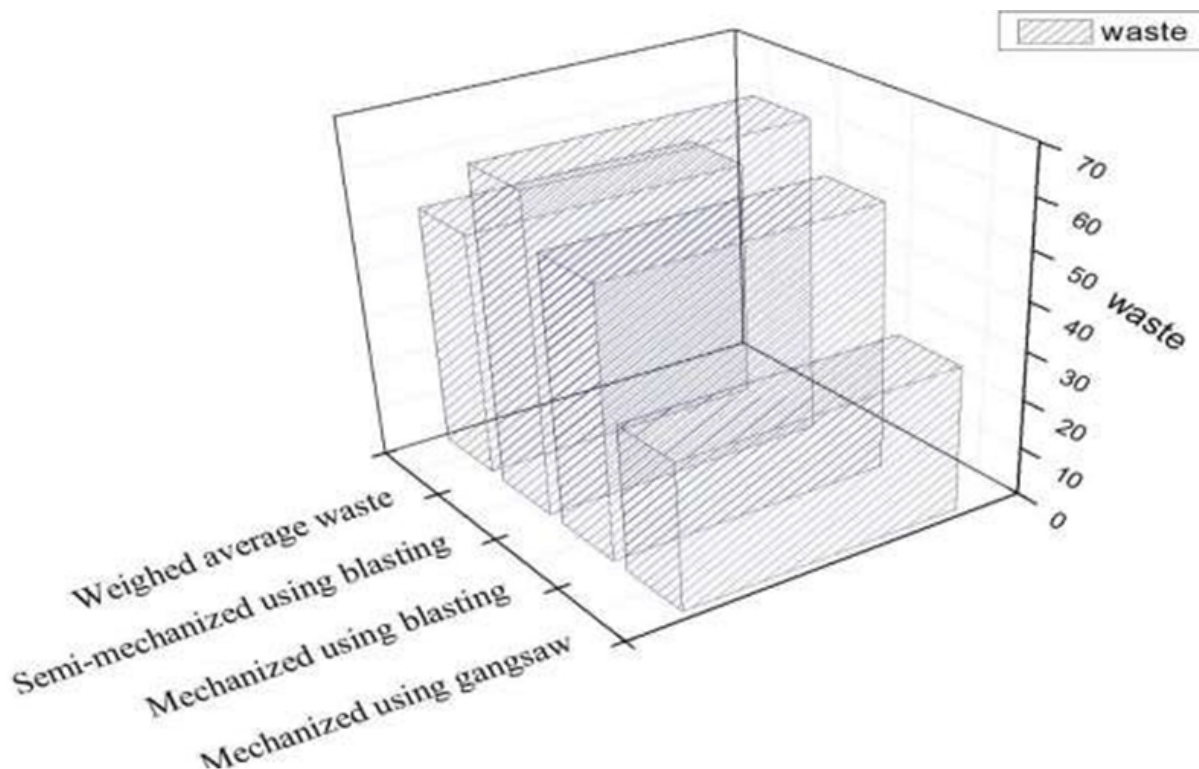


Figure 4. Percentage of Waste at Quarrying

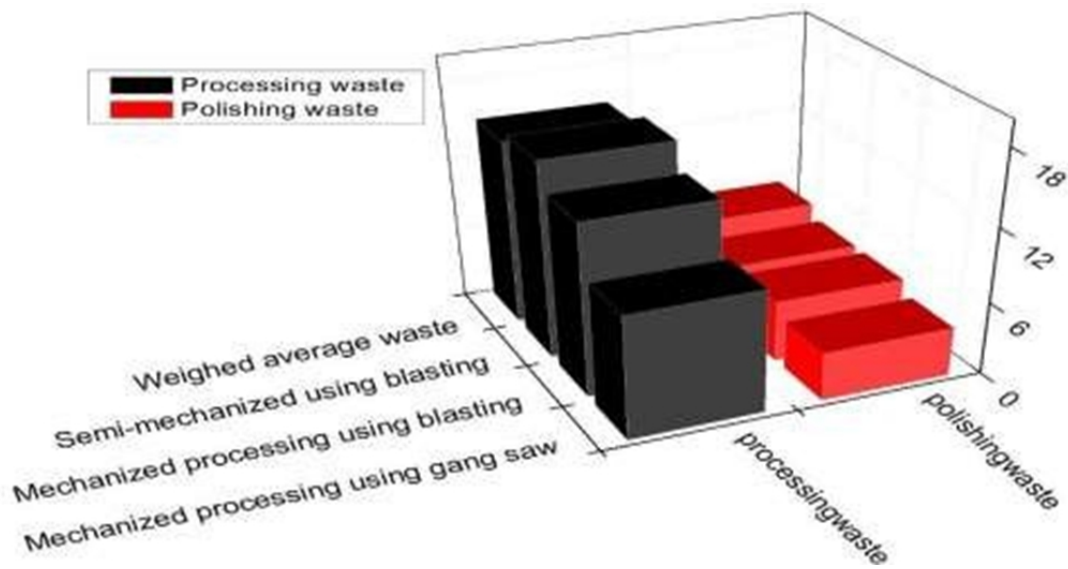


Figure 5. Percentage of Waste at Processing and Polishing

reverted back to quarries to fill the pit area in order to reclaim the land and improve the landscape of the site.

After demolishing any building or construction, marble stones can be re-used for building other new construction by making certain modifications to the stones by cutting and polishing. The stone can be considered as a sustainable material through out the processes, since it goes through the cycle back and forth as shown in Figure 7. The lifecycle of marble extraction has been completely designed in the form in order to facilitate a better understanding of the whole process.

The stone and marble industry of Rajasthan has extremely high percentage of waste generation like solid marble waste, powder and slurry, which are the major sources for environmental degradation where marble quarries and processings are located.

The Life Cycle Analysis of the marble mining process shown in Figure 6 is designed logically keeping in mind all the five components of sustainability goal definition, inventory analysis, classification, evaluation and improvement analysis (Heijungs, 1992; Prajwal et al., 2019). Our main goal of the study is to reduce the waste generated at each stage of the extraction process, which clearly explains the goal of the study. The total LCA process is shown in Figure 6, the environmental interventions and substances, which are effecting the environment, are clearly explained.

Marble waste and marble slurry needs to be explored as a replacement for conventional raw materials (Mali et al., 2018). Some of its utilities can be "As filler material for road embankments, for manufacture of bricks, manufacture of portland cement, manufacture of ceramic tiles, manufacture of thermoset resin composites, manufacture of lime, manufacture of activated calcium carbonate, hollow blocks and wall tiles, manufacture of ground calcium carbonate, as a neutralising agent and filler for paints and rubber, as a concrete aggregates, as an alphalt filler, in waste water treatment, in the treatment of sewage sludge to quell abnoxious fumes, in the filter beds as screened aggregate".

Marble waste produced from the extraction, renovation and demolition of buildings and other constructions is considered priority waste and is generated several million tons globally. Recycling and utilization of this waste would be a important contribution to the environment lead to sustainable development towards adoption of zero waste principle.

Marble waste can (Pathak, Kumar, & Jha, 2014) be used to produce innovative Nano-composite acrylic sheets were produced by free radical polymerization of Methyl Methacrylate (MMA). The study of physico-mechanical properties showed an improvement of adhesion between PMMA/SiO₂ nano-composites and (MWG) (El-Bashir & Hendi, 2009). Adding of SiO₂ induced an good

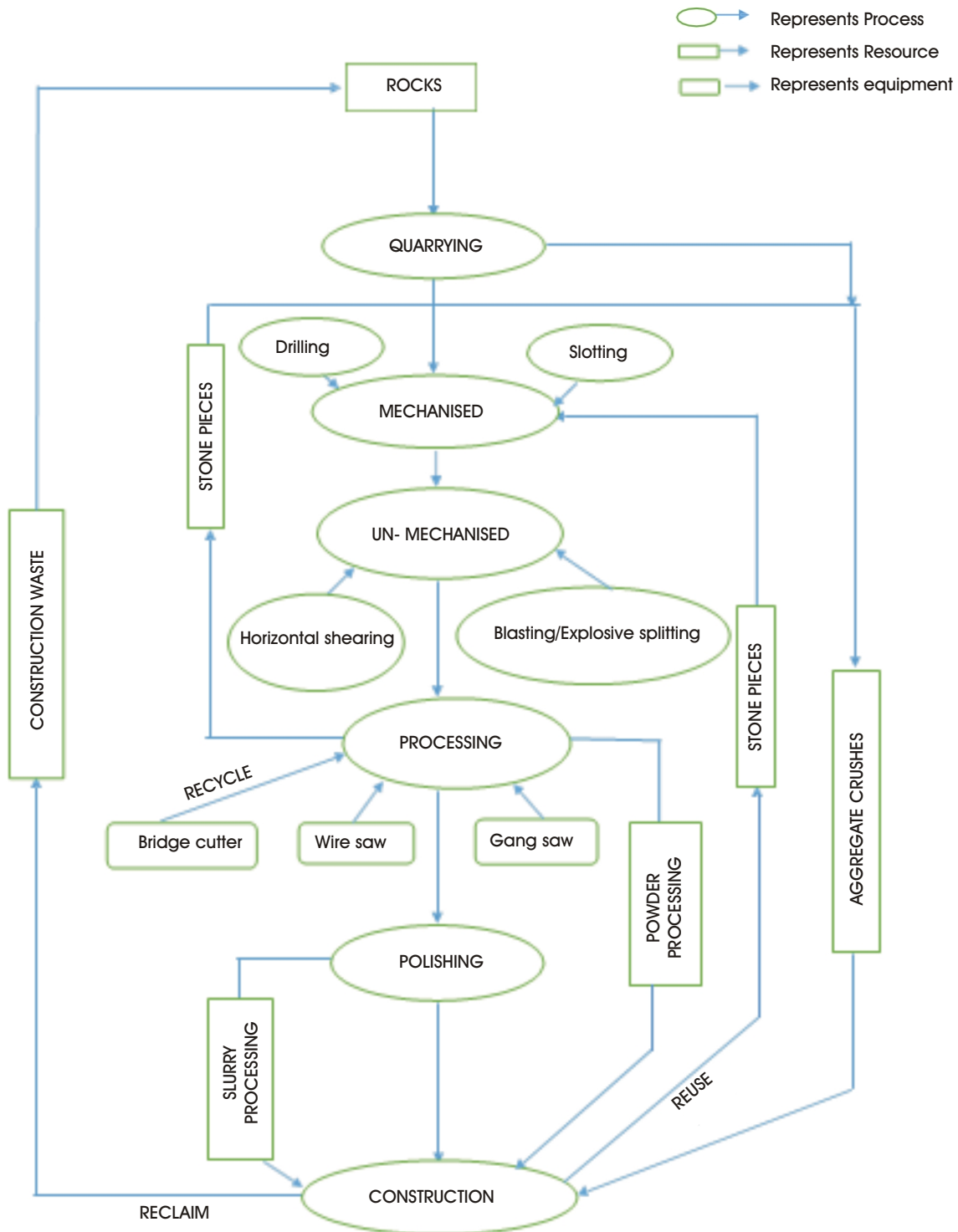


Figure 6. Life Cycle Assessment of Marble

development of the abrasion resistance of PMMA matrix. The manufactured nano-composites sheets are cheap in comparison to marble and own the capability to have extensive range of delightful colours due to the presence of

marble stones in a polymer matrix. In addition, the pieces display other specific properties such as light weight, colour stability, electric insulation, low water absorption and excellent mechanical properties (El-Bashir & Hendi, 2009).

Removal of copper (II) from samples by sportive initiation using Powdered Marble Waste (PMW), which are extensive and cheap and may signify an environmental problem, as the effective inorganic sorbent and oleic (HOL) as the surfactant. The main parameter's (i.e initial pH, sorbent, surfactant and copper concentration's, stir times, ionic strength, temperature and the presence of foreign ions) influencing the floatation of PMW and or Cu (II) were examined. The procedure was positively applied to recover Cu (II) spiked to some natural water samples (Ghazy, Samra, Mahdy, & El-Morsy, 2004; Haddadou, Chaid, & Ghernouti, 2015).

Al-Zboon and Al-Zou'by (2015) have studied the possibility of recycling stone cutting slurry in concrete production as a replacement of portable mixing water. The results showed an enhancement of concrete and motor characteristics results emphasized the feasibility of reusing slurry sludge in concrete and mortar production.

Hameed, Sekar, Balamurugan, and Saraswathy (2012) made use of Crushed Rock Dust (CRD) in concrete mix will reduce not only the demand for natural sand but also the environmental problem. In brief the utilization of CRD will turn waste material into a resource. But, limited research has been done to discover actual utilization of CRD in concrete mix. Zain, Safiuddina and Yusofa (1999) recommended that the CRD in the aggregate. An ideal spot is one where minimum waste is generated which not only brings prosperity to the mines, but also assists in preserving the natural endowments of nature.

4. Sustainability Study

Marble industry can be simulated for sustainability using doughnut-modelling technique. Doughnut model has been used to represent the management strategies in safe and sustainable environment. This model has two rings internal and external. The internal ring resembles to social basis under which people can live safely away from the ecological problems (Wenger, 2004; Hanieh, AbdElall, & Hasan, 2013). The outer ring of the model represents the ecological ceiling above which human beings will be exposed to ecological hazards due to the air & climate pollution, and land changes besides other impacts that change human and nature (Hanieh et al., 2013).

The doughnut model says us the fact that as far as the size of any (process or method) is in the measured range then it is said to be sustainable. Moving near the center of the model implies decreasing the production of the system and growing the safety of the model, while moving away from the center of the model implies increasing the environmental hazards with increasing the production & productivity. This clearly shows that the donut model is a compromise among the production and consumption, which is considered as Index of sustainability or Sustainability Index.

Environment Sustainability Index (ESI) = Production/ consumption

Here we interpret as the Environment Sustainability Index (ESI) because we are more concerned decreasing the total waste generated by improving the productivity of the model. So, let us consider two systems or two stages of the process quarrying and polishing and try to examine how to increase the ESI of the processes.

Study the sustainability doughnut models of three activities one sustainable quarrying, second the sustainable processing and third sustainable construction. If we see in detail the quarrying process in Figure 7 the four activities like explosive splitting, overburden removal, bench drilling, crushing are the activities with improvement of these will



Figure 7. Doughnut Model for Quarrying Process

increase the productivity/production but will decrease the sustainability and increase the ESI of stone and marble industry.

If we look at the remaining activities, which are the outcomes of quarrying like accidents & risks, waste generated, health hazards and noise pollution are considered as consumables because these are the activities caused with the expenditure of money for each activity. Enhancement of these activities leads to increase in the sustainability of marble industry.

If we look at doughnut model of processing as shown in the Figure 8 the four activities like cutting waste, polishing waste, dressing waste and transportation with the enhancement of these will decrease the sustainability or ESI.

Rest of four activities Accidents & risks, health hazards, water consumption/slurry waste and noise pollution which are the consequences of processing of the stones. Optimization of these activities can increase the ESI of the model.

Doughnut model of construction in Figure 9 the four activities unloading, arranging and distribution, handling and advanced cutting with the enhancement of these will decrease the sustainability or ESI.



Figure 8. Doughnut Model for Processing



Figure 9. Doughnut Model for Quarrying Process

The remaining activities Accidents and risks, waste generated, construction and lining which are the results of the construction. With the optimization of these activities will increase the ESI of the model.

Three models quarrying, processing and construction can be connected to with one other using donut model in order to represent the total LC of marble industry from quarrying to construction through processing as shown in Figure 10.

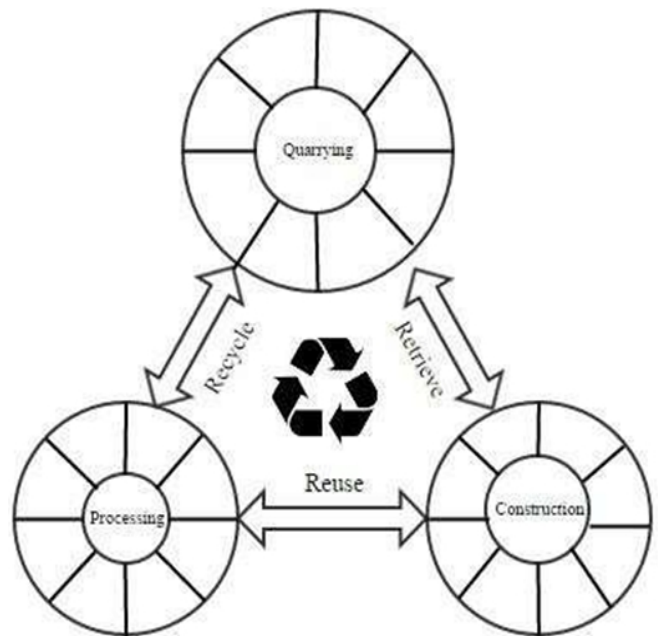


Figure 10. Doughnut Model for Stone and Marble Life-Cycle

5. Sustainable Model for Marble Industry

Marble industry can be modelled using the sustainable model to know the relation between different parameters influencing the sector. Three different models are represented by an interfered circles namely quarrying, cutting and construction represented in Figure 11. The main task of the quarrying is to cut/slice the stones load it on to the trucks and transport it to the cutting site. In quarrying a professional skilled labor is required in order to reduce the waste produced at quarry. Cutting factories are accountable for shaping, slicing and transferring the cut stones to the building field. Simultaneously, quarrying is also accountable for the distribution of aggregates of stones to the building site. So both quarrying and construction yields waste and needs to recycle this produced waste.

To enhance sustainability, the marble waste from slicing area is carried back to the quarrying where it is crushed and transferred in different shapes and sizes to building and concrete factories. In certain circumstances when an old building is destroyed the marble stones are directed back to slicing sites to be restructured and re-claimed again in new buildings. The remaining waste from the destroyed building can be recovered and sent to abandoned quarries to fill them for reshaping the landscape.

Processes carried in three sectors include sustainable terms: water, energy, environment and safety. As water is a scarce resource in Rajasthan, it is crucial for any process to take into account recycling and reusing the water used in cutting workshops where water is used highly consumed. Energy conservation is strictly required. Other issue linked

with the three sectors is the environment pollution. This environment is represented by air and water pollution. In slicing areas the air pollution is reduced by diluting with water but this leads to pollute the water. But current quarries use sophisticated cutting technologies like water jet machining which can be maintained by following standards and precautions while cutting and handling process.

It is clear from the sustainability models that by increasing the production of items and decreasing the consumption of items best result between production and consumption can be achieved by taking into consideration the supplies, demands and requirements of the Rajasthan region.

6. Type of Cutters used by Local Industries of Rajasthan

In case of all materials the selection of tool for cutting is really important in terms of efficiency as well as tool wear shown in Figure 12. This fact can also be extended for cutting and milling operations. Diamond tools are widely used for machining hard materials and stones. During cutting or milling operation it is important to choose the appropriate dimensions like (diameter, insert cover, angle of tool) shown in Figure 13. In case of marble, the properties that influence are diameter, material and type of segments/bits, concentration and size of diamond grains in the segments.

Inserts that are generally used for cutting marble and stone is made of two components (metal matrix + diamond grains). According to the hardness of the marble this composition can be changed. If the hardness number of any stone is less then diamond powder can be replaced with other constituents in order to reduce the cost of the tool (Gyurika, 2011).

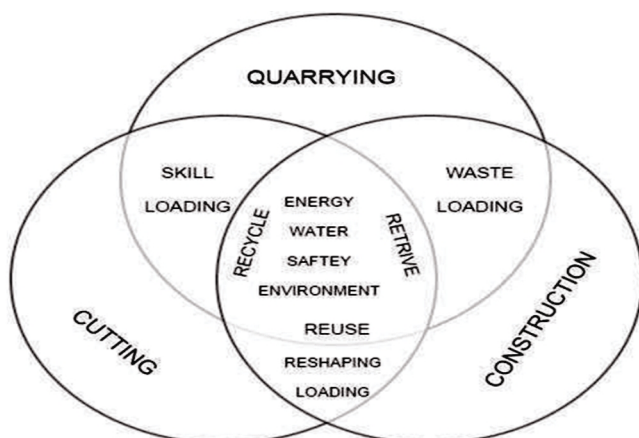


Figure 11. Sustainable Model for Stone and Marble

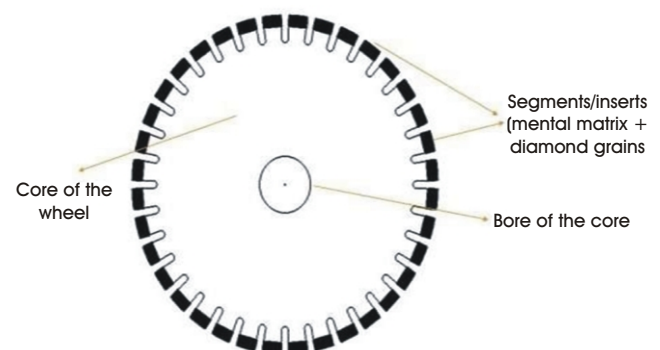


Figure 12. Parts of Circular Diamond Cutter

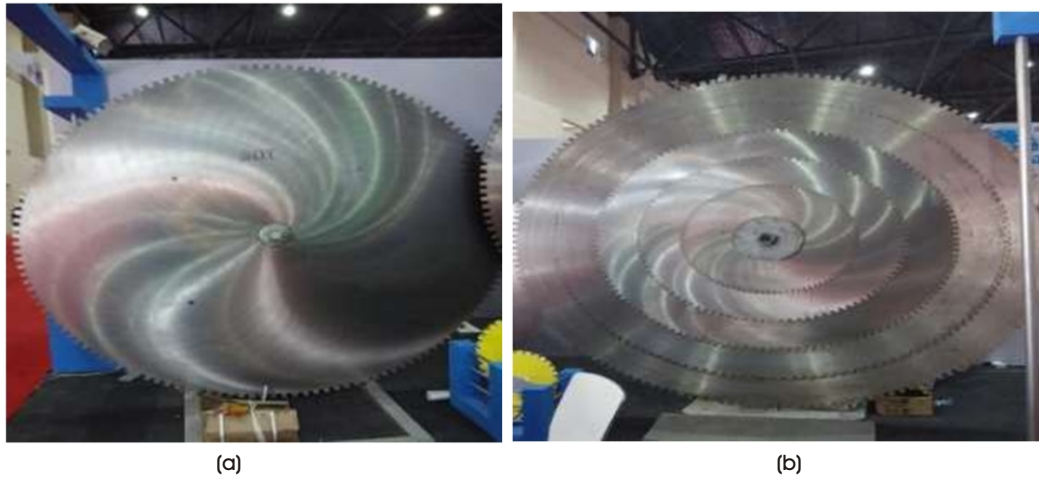


Figure 13. (a) Single and (b) Multi-Blade Circular Diamond Tools

The following are some of the cutters/blades that are used for slicing marble and stone in different regions of Rajasthan.

6.1 Single Circular Cutter Blade and Multi Circular Cutter Blade

The single circular blade has different diameters ranging from (800 to 3000) mm and its corresponding bore hole varies from (100 to 150) mm with different segment thickness and height as per the customer requirement. In the same way a multi circular blade is available with different diameters ranging from (35 to 1600) mm and bore hole ranging from (50 to 100) mm with different segment height and thickness as shown in Figure 13.

The core of the cutting tool is typically made up of different quality of steels that solely depends on whether the segments/inserts are attached to the core by soldering or welding.

6.2 Diamond Wire Cutter

Diamond wire sawing is a very old technique and is in use for approximately around 30 years before (Tönshoff & Hillmann-Apmann, 2002). They have indeed revolutionised cutting processing by increasing the Material Removal Rate (MRR) and surface finish when compared to other conventional sawing methods. Now-a-days diamond segment tools are widely used for soft, hard and brittle stones.

The efficiency of the tool is an important criteria to be considered while performing the experiments. The cutting

ability of the wire is generally influenced by various parameters like cutting force, speed, feed and the configuration as (diamond grain size, its concentration and bonding) between the diamond segments of the wire saws, the Figures 14 and 15 show's the wire saw and the beads used for cutting marble.

6.3 Straight Blade Cutting Tool

The Diamond wire cutter tools are little bit expensive when compared to a straight blade cutting tool. These tools are widely used by small scale industries of Rajasthan. The blade mainly consists of a steel core of required length according to the length to be cut and the segments/beads are either sintered or welded at the end of the tool, the



Figure 14. Diamond Wire Beads/Segments



Figure 15. Diamond Wire

design of tool is shown below in Figure 16.

The segments are mostly made of (metal matrix + diamond grains) embedded into it shown in Figures 17 and 18. These segments are fabricated locally, the composition of the metal matrix depends on the hardness

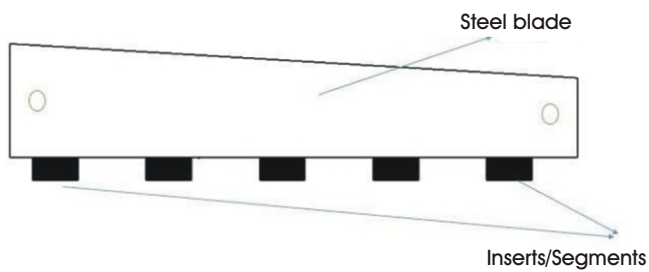


Figure 16. Straight Blade Cutting Tool with Segments



Figure 17. Segments of Straight Blade



Figure 18. Diamond Wire

of the marble to be machined. A survey was conducted in seven different industries (A, B, C, D, E, F and G) located nearby regions of Rajasthan (Pathri, 2015). The segments collected were characterized using SEM, EDS to find the composition of the metal matrix (Figure 19). Further, their life was calculated and tabulated in Figures 20 and 21. The characterization revealed that iron and silicon powder were used as abrasives since the cost of availability of these materials are less (when compared to the circular and wire saw) for the metal matrix with diamond particles suspended in it. For a harder stone or marble to be cut then the iron or silicon particles are replaced by cobalt or nickel according to the required composition.

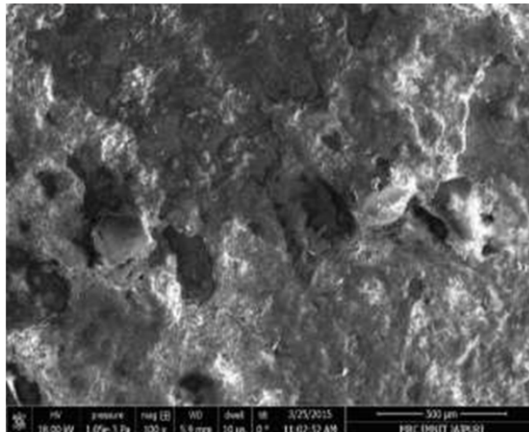
The parameters of the tool effecting the cutting speed and the life of the blade is listed in the Table 3 and their life in hours and months is shown in Figures 20 and 21 .

The survey results of different industries are listed in Table 4

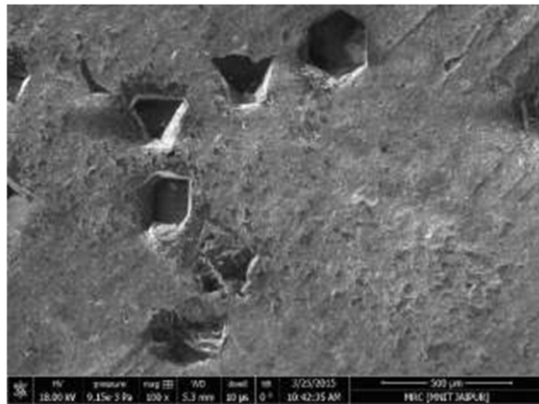
7. Energy Audit and Waste Disposal's

After the marble is quarried it is sent to the local industries for further processing to be done on the natural stone. To do the energy audit it's important to look in detail what are the different processes that the natural stone undergo before it emerges as the final product ready for the construction. So, by focusing on different steps a natural stone encounters we can easily able to calculate the energy consumption at each stage of the process.

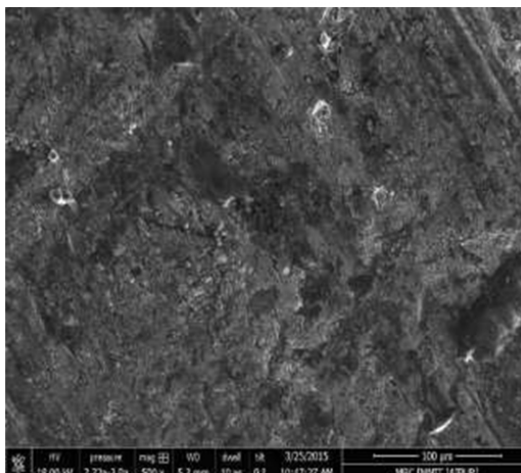
The following are the different activities of the processing



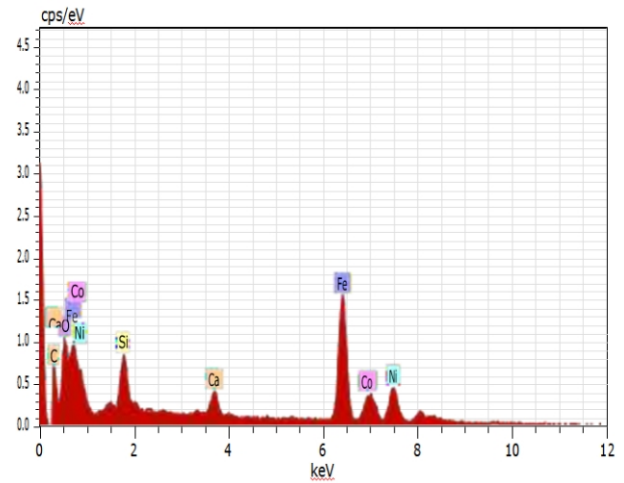
(a) Industry A-tool



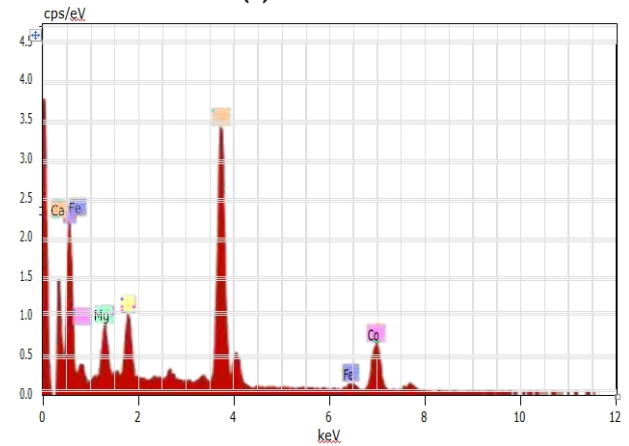
(b) Industry B-tool



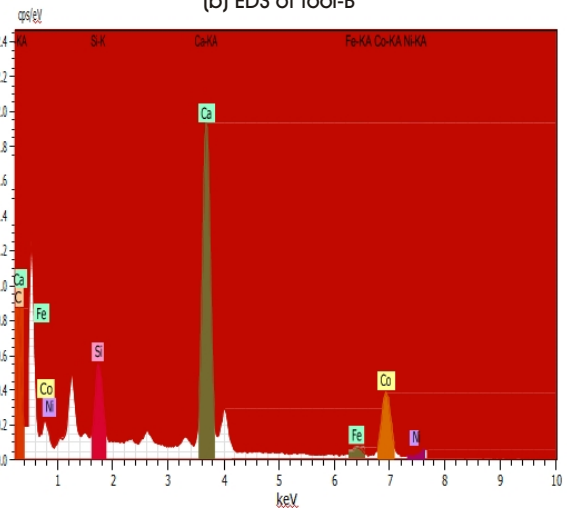
(c) Industry C-tool



(a) IEDS of tool-A



(b) EDS of tool-B



(c) EDS of tool-C

Figure 19. SEM and EDS Analysis of Tools of Industries

that a marble block undergoes before finally emerges as slab/tile which is used in construction.

Receipt of Marble Blocks: The marble blocks received from the quarrying site are unloaded in the gantry yard with the

help of gantry cranes (Figure 22).

Trimming of Marble Blocks: Trimming is done from all sides to make it a perfect block then further it is inspected for any defects in the block. If there are any defects in the block,

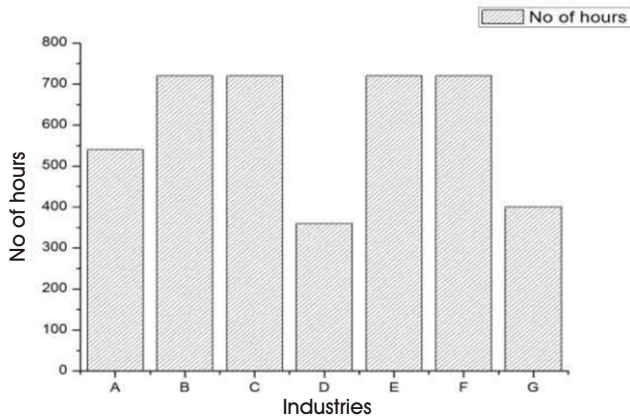


Figure 20. Tool Beads/Segments Life in Hours

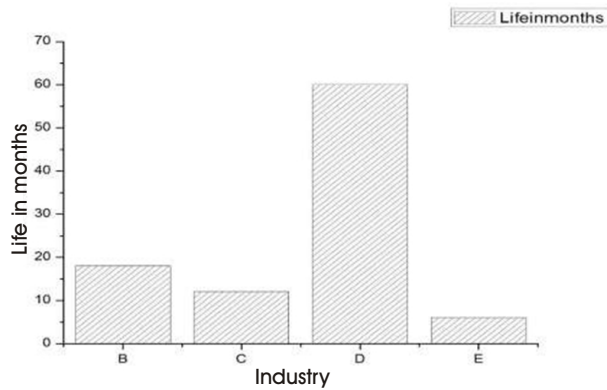


Figure 21. Life of Cutters

reinforcement processes is carried out (Figure 23).

Block Reinforcement: Before sending the brittle marble blocks to gang saw machine for sawing, the blocks are reinforced with fibre glass net and a binding agent is applied. Block is then left for 24 hours for curing. This process ensures the minimum breakage while cutting operation (Figure 24).

Sawing Process: The reinforced blocks are sent for slicing using Gangsaw machine to required dimension. The blocks are generally placed on a trolley and is placed

	Cutting Speed	Blade Life
Segment Bond Hardness Harder	slower	Longer
Diamond Quality Higher	Faster	Longer
Diamond grit size bigger	Faster	Shorter
Diamond Concentration Higher	Faster	Longer
Segment Width Thicker	Slower	Longer
Segment height Higher	Slower	Longer
Cutting Depth Deep	Slower	Shorter
cutting Pressure Higher	Faster	Shorter
Material Hardness Higher	Slower	Shorter
Material Abrasion More	Faster	Shorter
Aggregate Size Larger	Slower	Shorter
Cutting with coolant	Higher	Longer
Rotation speed Higher	Higher	Longer
Operator's Experience More	Higher	Longer

Table 3. Parameters Effecting the Speed and Life of Tool

below the blades for cutting (Figure 25).

Net Reinforcement of Slabs: Glass fibre reinforcement is applied on back of the marble slabs to strengthen them and enable safe handling while carrying (Figure 26).

Grinding Process: After the 1st stage of epoxy treatment of the marble slabs they are processed by the grinding machine and shifted to the resin line for final epoxy resin treatment (Figure 27).

Resin Treatment: Most of the natural stones have hairline cracks, minor cracks which required to be treated. State of arts machines used to enhance the slabs. The slabs are first dried in the heating chamber, high quality resin is applied, vaccumization is done to remove air bubbles, and polymerization of the resin is done through heating chambers. This process helps in filling even the invisible crack and produces good quality slabs (Figure 28).

Polishing process: Polishing is done using line polishing machines, these machines make the slabs even and

Industry	Machine	Stone	Material of Cutter	Sludge Formation	Cooling Type	Safety Device	Lubrication
A	Gang saw	marble	iron	10-15%	WET	-	-
B	Gang saw	marble	-	25-30%	WET	Support & Safety	-
C	Block cutter	Marble and sandstone	Pure steel	33%	WET	No need, shoes only	Gear oil 180 No.
D	Water jet machine	Wood to M/S	Carbide+Iron (nozzle)	-	WET	Avoid hand on practice to nozzle	-
E	Circular single and multi-cutter	Granite	-	30%	WET	-	Grease, Gear oil 90 No.
F	Circular saw	All stones	-	4-5%	WET	-	Gear oil & grease
G	Block cutter	Quartz and Sandstone	2% Nickle + Steel	37.5%	WET	-	Gear oil

Table 4. Specifications and Parameters of Various Industrial Machines



Figure 22. Gantry Cranes unloading Marble Blocks



Figure 23. Trimming Machine



Figure 24. Reinforcement Process of Marble Blocks



Figure 25. Sawing Blocks using Gangsaw Machine



Figure 27. Grinding Process



Figure 26. Net-reinforcement of Marble Slabs



Figure 28. Resin Treatment Process

surface finish is enhanced to get shiny and smooth surface (Figure 29).

7.1 Energy Audit for Industry

Most of the energy expended in a marble production process runs through the large-power engines (Table 5). Energy consumption of each machine is calculated using the following equations. Electric power supply to a 3 phase AC motor:

$$P_{kW} = \eta_m 1.73 U I PF / 1000$$

where,

P_{kW} = power (kW)

η_m = motor efficiency

U = voltage (V)

I = current (A, amps)

PF = powerfactor

Energy consumed = $\eta_m 1.73 U I PF T / 1000$ T = runtime



Figure 29. Line Polishing Process

8. Waste Disposal Practices

Stone industry has a severe impact on the environment in both sites; quarries and cutting workshops. In quarries, the rock extraction process is accompanied by dust, which pollutes air besides to the wide excavations that leave severe effect on landscape and soil. In slicing workshops, the problem of dust is moderately treated by providing water to the slicing process which decreases air pollution but on the other hand, it causes water pollution and forms big basins of slurry that need to be solved. The wet slurry generated by the processing industries is generally diverted to a sedimentation tank. In almost 90% of the industries, the settled slurry is pumped out in to adjacent agricultural lands and left to dry there, as shown in Figures 30 (a, b)

Some of the industries do employ a mud dehydration plant for recycling of water. The filtration plants installed employ flocculation agents for quick separation of water and slurry. They help in preservation of water to a great extent. Here we found the sedimentation area of near about 6 x 24 m². The filter tower as seen here is approximately 25 m in height. However, they were found to be ineffective in reducing the volume of the waste to a large extent. Some of the industries pump the slurry on to tankers and transport the slurry presumably for dumping in disposal sites earmarked by the government. However, most of them dump the slurry in vacant forest areas or on the road side. There is no proper arrangement for collection of waste material in most of the processing units of marble. Except at few large processing

Type of Machine	A	B	C	D	E	F
Gangsaws	125*2 hp	150 hp	150	125*3 hp	150*2+180 hp	150*4 hp
Runtime for Gangsaws	12 hrs	10 hrs	12 hrs	12 hrs	12 hrs	10 hrs
Dressing machine	50 hp	30 hp		50 hp	30 hp	30*3 hp
Runtime for dressing machine	5 hrs	6 hrs		6 hrs	6 hrs	6 hrs
Block cutter			50 hp			
Runtime for block cutter			10 hrs			
Polishing machine		30*6 hp	30*3 hp			30 hp
Runtime for polishing machine		4 hrs	4 hrs			5 hrs
Line polishing machine			14*14+7*2hp		12*14+7 hp	
Runtime for LPM			6 hrs		4 hrs	
Bridge cutter			10 hp			10*6 hp
Runtime for bridge cutter			6 hrs			8 hrs
Energy consumption (kWh)	5.6225	4.152	6.8854	8.304	11.4872	12.4041
Monthly units consumed	168.675	124.56	206.562	249.12	344.616	372.123

Table 5. Energy Audit of Different Industries



(a)



(b)

Figure 30. (a) Sedimentation Pits, (b) Sedimentation and Filtration Towers

units, segregation of waste is practically non-existent. The processing industry in Rajasthan mostly does not employ filter presses. In most of the cases there is contamination of polishing waste with the cutting waste (produced at circular raw and / or gang saw). Large amount of marble slurry is discharged as a waste either to a vacant land or to a surface water source located in the vicinity of the units. There is a general lack of seriousness towards effective disposal of the sludge and slurry to the identified/ specified site of disposal; for reasons like expenditure involved in handling the stone waste, remoteness of locations of the site of disposal, time and efforts involved in handling the waste material etc.

Conclusion

The work emphasizes on the importance of stone and marble sector in the north western state of India, Rajasthan. Through, this region India has more than 11% export share in world's total stone exports. It produces more than 27% of the total stones produced throughout the world but still this sector suffers from many problems and drawbacks which needs to be tackled in order to increase the productivity and address the environmental challenges. Since, the natural stone is a non-renewable resource it should be used in the most efficient way. The complete stone extraction process is detailed in this paper by considering the sustainability study of two segments quarrying and

processing. It clearly explains how sustainability can be achieved by considering the Environmental Sustainability Index. This sector has a major contribution to country's economy but requires major improvements in technologies, methods that are being currently used including adapting new technologies. Different cutters that are used currently in Rajasthan explained with neat sketches. A survey was conducted in seven industries at different regions of Rajasthan to realize the type of tools used by them for machining. A number of locally made inserts/segments by the industry were collected and characterized to know the composition, these tests revealed that most of them are made of iron and silicon powder for the matrix material, and these compositions can be varied depending on the hardness of the marble to be cut.

Full energy audit is done for the industries to calculate the energy consumption. A detailed layout of marble block processing (Figure 31) to final slab production is explained with neat sketches. While processing these blocks to slabs, tons of marble slurry is generated whose disposal is a great problem faced throughout the world. Various disposal methods that industries currently employs is discussed.

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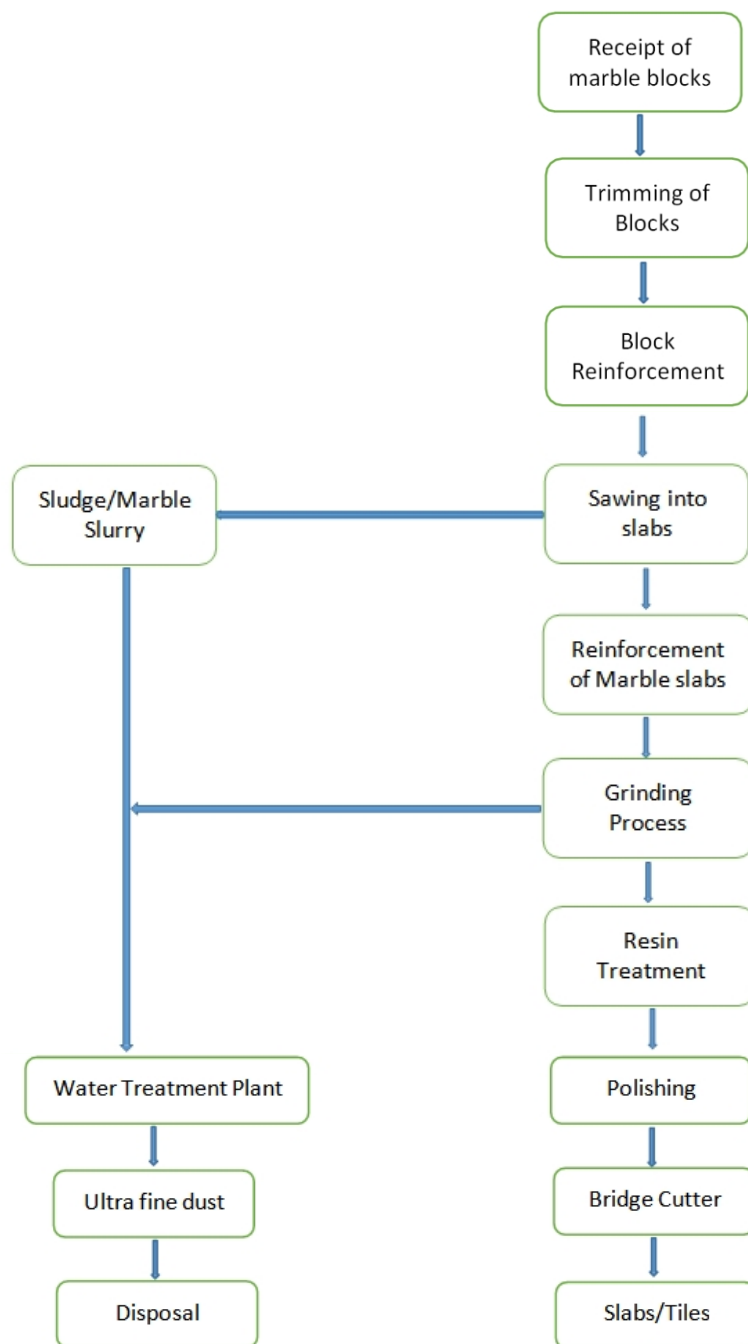


Figure 31. Marble Processing Layout

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