Cutting Tool for Marble & Granite: A Review

Ravi Kant Gupta¹ and Ravi Kumar Gupta²

¹,² Manipal University Jaipur, Rajasthan, India

ravikant.gupta@jaipur.manipal.edu, ravikumar.gupta@jaipur.manipal.edu

Abstract. Influence of marble and granite stones on diamond cutting tools during processing of raw stone was carried out. Tool wear and life is the main cost of diamond cutting tool with diamond-impregnated segments. Variety of marble and granite stones are available in India with a large market demand (domestic and international requirements) were cut by a stone processing Industry. Based on study of existing cutting tools and methodology followed for cutting the marble and granite, new composition with varied properties of the binder used in the cutting tool to increase wear resistance is identified.

1. Introduction

Rajasthan is the mainstay of the Indian marble and granite industries and has over 90 per cent of the country's marble and granite deposits spread over the entire state. Marble and granite produced in Rajasthan are used in architecture and construction because these are common and can possess a variety of textures and colors. Rajasthan has a huge concentration of marble with reserves dissipated in various districts of Dungarpur, Sirohi, Nagaur, Rajsamand, Udaipur, Banswara, Jaipur, Bhilwara, Ajmer, Bundi, Alwar and Pali [1]. Makrana, a small town in Rajasthan, has been famous for its marble mines since ancient times. The different colors found in Rajasthan marbles are Green, Jhiri Onyx, Phalodi Pink, Forest Brown, Agaria White, Makrana Albeta White, Makrana Dungri White, Makrana Kumari White, Ambaji White, Indo-Italian, Babarmal Pink, Bhainslana Black, Agaria White [1]. Granite reserves in Rajasthan are estimated at 8479 million cubic metres and are spread over in the districts of Barmer, Jalore, Pali, Sirohi, Alwar, Jaipur, Jhunjhunu, Tonk, Ajmer, Bhilwara, Sikar and Udaipur. Prominent processing industries of granite processing and mining in Rajasthan is Jalore with hundreds of small stone processing plants. The mines in Jalore, Barmer and Jaisalmer produce a wide variety of stones of excellent quality and colours. Marble is relatively softer material with Hardness 3-4 in mohs hardness scale. Granite is relatively harder material with Hardness 5-7 in mohs hardness scale [2].

To cut granite (marble) or fabricate something out of granite (marble), it is necessary to use a material that is considered to be harder than granite (marble). Few tools are hard and tough enough to cut through granite (marble). Diamond-tipped saw blades are the most widely used blades for cutting through granite (marble). Using improper tools can compromise the granite (marble) cutting operation. Proper selection of a cutting tool is also an important criterion [17]. Cutting tool should have right composition so that tool life will be more and wear should be minimum.

As marble and granite processing industries are facing the market competition as low cost production, short time of delivery and high qualities. But it is difficult to achieve these requirements due to the limitations as the tools available have shorter operational life because of the frequent wear of the cutting tools [3]. The tool does not produce the required qualities and quantities due to the varied properties of the marble and granite available in Rajasthan.
The paper presents the study for existing cutting tools and methodology followed for cutting the marble and granite, and suggests a new composition with varied properties of the binder used in the cutting tool to increase wear resistance which will increase the operational life. The new tool will be manufactured and results will be compared with the available tool.

2. Study of cutting tools and methodology followed for cutting the marble and granite

India’s 10% GDP is based on construction activity, 7-8% construction industry growth in the next 10 years, $1 trillion – investment in infrastructure (2012-2017), $ 650 billion – investment in urban infrastructure in the next 20 years [4]. India has one of the largest reserves of marble and granite in the world and exported Rs 2,600 crore (Rs 26 billion) worth of the stone last year that is approximately 85-90 %. Marble and Granite exports this fiscal are expected to touch Rs 2,800 crore (Rs 28 billion) and nearly one-fourth of these exports is accounted for by monument stones. Granite and Marble industry in Rajasthan state growing 50% annually and mining Rs 800 crore annually. It form 95% of India’s dimensional stone export. Marble and granite is necessity of each and every house, multi-storey buildings, offices etc [4].

As far as Granite, marble & decorative Stone are concerned; the present indigenous R & D sector is negligible. Entrepreneurs have been able to get the technical R & D help from their overseas counterparts and clients. Best of the technology has come to Granite and Stone industry through aggressive marketing by overseas manufacturers of machinery and processing industry of stones. For granite, it is generally acknowledged that the industry has to meet the cost for commercial information and R & D [5]. It was decided that there should be a permanent arrangement for addressing the R & D related issues of granite through National Institute of Rock Mechanics – a research institute of Ministry of Mines [5].

The sequence of events which brings marble and granite stone from the quarry to the home has not changed much since stone entered the homes of the ancient Greeks. Large blocks of stone are cut from the quarry. From those blocks, thin pieces of stone are cut called slabs. The slabs are then shaped and polished and shipped for installation [6]. What has changed dramatically over the years is the type of machinery used in this age-old sequence. Marble and granite stones are cut with conventional tools and often require slow and expensive processes. Linear and circular saws, grinding wheels, wire saw pearls among others, are diamond cutting tools used in the slabbing, cutting, and polishing of marble and granite stones in general. There are a wide range of types of materials used in the manufacture of these tools, but the most employed is the system metal bond matrix - diamond crystals [7]. Diamonds are impregnated in the metal matrix via two ways: electrodeposition or sintering. The metal matrix selection is based on the abrasivity of the material to be cut or polished. For highly abrasive materials such as concrete, SiC, Si3N4, Al2O3, tungsten bond is used [8]. Cobalt bond is employed in the cutting of materials whose abrasivities are similar to the granites. Bronze, cobalt bonds and its alloys are used for marbles. Brass, bronze or copper bonds are employed in the cutting of ceramics, glasses, and nonferrous metals [9]. The sintering is normally accomplished by hot pressing. In this case, the powder (in the desired form) is submitted to sintering at the same time in which it is pressed into a mold. A method to process diamond pearls for cutting stones, where the metal matrix bond + diamond crystals mix is confined into holes of a graphite mold. This mold is put into a resistive vacuum furnace chamber coupled to a press. The press punches conduct the current for the green bodies sintering, at the same time that press them into the mold holes [10].

Design and fabrication of diamond cutting tools requires a low compressive strength, wear resistance and good abrasion properties. Further, it retains its properties while machining so that due abrasion wear resistance should be low [11]. For cutting stones cobalt base tools are used, but increased cutting speeds result in harsher conditions in machining, cost of cobalt and diamond particles loosen during machining [7]. Figure 1 shows loose diamond impregnated segments used for cutting marble blocks on gang saw machine. The work presented in this paper examines not only the performance of wear resistant but also the economical cutting tools produced.
3. Requirements of improving Cutting tool used for Marble and Granite

The most serious contender of the Indian natural stones industry is China, especially in the granite trade due to its lower prices. Spain is an important contender too. Spanish industries investing mainly in the infrastructure and machineries involve stone cutting to increase their production capabilities to a greater extent. There are many varieties of Marble and Granite such as Makrana Marble (used in Taj Mahal), Rajnagar Marble (the world’s largest marble-producing area), Andhi Marble (a dolomitic marble with intrusions of tremolite), Salumber Marble (also known as Onyx Marble), Rajasthan- Abu Black (a rare black textured marble) are available in the state [12].

For the development and progress as well as removing obstacles to achieve rapid and constant growth Federation of Indian Granite and Stone Industry (FIGSI) has been working since 1983. The principal objective of FIGSI is the promotion of the Natural Stone Industry, acting as a bridge between Industry and the Government in bringing constant improvement in mineral regulation, policies, processes, systems and procedures. FIGSI also promotes the gradation of technology aimed at mine safety, productivity, cost efficiency and quality improvement. It is initiating to start an Institute for Research and Development as well as training to benefit the industry [12].

A large number of processing centres have been developed in the state at Makarana, Jaipur, Alwar, Ajmer, Udaipur, Nathdwara, Rajsamand, Morchana, Amet, Abu Road, Kishangarh, Banswara, Chittaurgarh, Sirohi etc. where more than 1100 gangsaws and 50 automatic tiling plants are in operation [13]. A large number of tiny units are also working. Since granite is a hard rock than marble, special cutting, grinding and polishing heads are used for rapidly cutting, grinding and polishing the slabs of granite. Our aim is to develop a better cutting tool, so that these manufacturing industries can be benefitted in terms of cost efficiency and quality production.

3.1. Relevance to India’s stone industries

India is endowed with vast natural resources of marble and granite in several states predominantly in Southern India, Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat and Bihar. Indian Bureau of Mines assessed marble and granite resources in India in the year 2000 [5]. An extensive deposits spread all over Rajasthan and are being actively exploited. As per the report, Rajasthan produces more than 60% of the country's marble and granite reserves.

The demand for granite and other decorative stones is increasing and is anticipated that the annual growth would be around 20%. Indian granite, marble and other stones have established very well in world market where our share of world requirement is 12% of the total world market, which is Rs. 25,620 crores and 18% in terms of tonnage. India has abundant resources, sufficient technical knowhow, large 164 quarrying and processing capacity, and can safely ensure export growth at the rate of 20% per year in coming 15 years or more. Domestic consumption of Granite stones is around Rs. 7,000 crores [5]. It is anticipated that the dimension stone industry for the domestic sector will also grow simultaneously with the development of Export Industry. Our country in the last few years is having a phenomenal growth in building activities and other infrastructural areas where the demand has picked up. The growth is continuing in domestic granite consumption and shall remain growing in the coming next 15 years. Projections for investment in Dimensional stone Industry Present investment in dimensional & decorative stone industry in India is estimated at Rs. 10,000 crores. It is expected that given the policy support, the total sales turnover of all the stones, which is today at around Rs. 15,000
crores will increase to over Rs. 44,788 crores by 2012, Rs. 1, 11,444 crores by 2017 and Rs. 2, 77,304 crores by 2022 considering an estimated growth rate of 20%. In order to meet the projections in next 15 years, it is estimated that further investment have to go up by about Rs. 2, 00,000 crores (including foreign investment) by 2022 [5].

It is suggested that the existing production houses in Rajasthan has to increase their production rates and qualities. This can be achieved by improving production methodology and resources used. One of the prominent resources is cutting tool. We suggest as part of this proposal to study the existing cutting processes and tools for fabricating cutting tool with improved wear resistance to achieve the requirements by the Rajasthan’s stone industries.

4. Challenge & Constraints for enhancing marble and granite cutting tool
Marble and granite production houses are using exiting branded tools for their cutting operation. So it is difficult to convince them to adapt new cutting tool with improved wear resistance and operational life. So we are planning to provide the experimental cutting tool to some of these production houses for the production and in return we will ask them to provide us the required information and feedback. Difficulty may arise in procuring the raw material required for fabricating the newer cutting tools with the investigated material composition and binder. But we have discussed some of the vendors; they will import the requested material for our experimental purpose. The experimental material may be costly.

Difficulty may arise in fabricating the investigated material composition as the fabrication using sintering process may not support the investigated material composition. So in that case we will investigate other fabrication processes or we will investigate material composition which is feasible by sintering process with different combination of temperature and pressure.

Study of available literature for cutting tools used for metal cutting and stone cutting. It is found that the binder martial has to be improved for increasing tool quality and life. It is also found that the production cost of marble and granite may be increase using different composition of tool material and binder.

The investigators are familiar with the cutting process and tools used for metal cutting operations. This knowledge will be extended for the investigation and development of cutting tool for marble and granite cutting. From the literatures, investigators have found that the extensive studies are available for metal industries but the investigation for marble and granite industries are very limited.

5. Preliminary Investigations
Marble and Granite cutting tools available in the market were designed and produced by many industries using different material compositions by wt% of each constituent. Typical compositions includes cobalt as binder material having 90% by wt, bronze 4% (Sn, Fe, C, O, N) and diamond particles 2 to 3 % by wt in marble and granite cutting tools. This composition may vary and depends upon the quality of stone to be cut. Literature shown that diamond concentration 50 (2.2carat/cm3; 0.44g/ cm3; 0.13 cm3 of diamond/ cm3 of tools) is used. Since this is the concentration used for cutting dimension stones [15]. Based on literature and industrial survey, a composition of a newer tool utilizing rhenium as binder material is under development and testing stages.

Production includes mixing of identified composition in the required proportion in a closed chamber, drying, and filling, followed by cold pressing of the raw powders in order to prepare mould. After pressing, the mould went through a solid state sintering process in a conventional sintering oven, where mould is sintered at high temperature and pressure and then it is cooled up to room temperature under controlled condition [16].

Stone cutting tool usually contains cobalt as binder and problems with such cutting tools are regarding the wear rate and tool life. The wear of diamond tools that were used to cut stone may result from complex behaviour and assembled wire saw used for extracting marble/granite blocks from mines as shown in figure 2&3. Abrasion, erosion, fatigue, and impact were effective simultaneously. Wear characteristics of diamond tools are well documented in literature, such as the reason for fracture formation and propagation on diamond particles, the relationship between diamond particle wear and
sawing area, the influence of temperature on diamond tool wear and the predominant wear forms of diamond particles [19]. The wear mechanism of diamond particles is abrasion, impact shock and fatigue, impact loading, and thermal shock. The wear mechanisms of diamonds are impact-shearing, fatiguing, pull-out, and thermal effects. The wear mechanisms of diamond particles are adhesion, friction, diffusion, and fracture wear. The main damage forms of diamond particles are cracks, fractures, scratches, and pits. The main wear mechanisms of the diamond particles are abrasion, fatigue wear, impact wear, and flush erosion when using the frame saw to cut marble or granite.

5.1. Abrasive Wear
Granite is composed of hard and tiny abrasive minerals, such as quartz, plagioclase, and orthoclase. Due to abrasion between diamond tools and stone is responsible for the wear of diamond tools that are used to cut granite [19]. Abrasive particles of the cutting tool rubbed the surface of the stone creates Grooves, cracks, and scratches on the surface under the reciprocating sawing action of the frame saw/circular cutter or in gang/block saw.

5.2. Fatigue Wear
Diamond particles have characteristics of high hardness, low strength, large brittleness, and uneven internal organization [20]. In diamond cutting tools defects and pores also exist. Diamond particles are not damaged immediately but loosen from the binder material and propagate along defects or pores in diamond particles after cutting forces act on diamond particles cyclically for a period of time. Fatigue wear is also a normal wear but cracks developed on tool are converted in to macro-cracks very easily, and then fractures occur on the diamond particles.

5.3. Impact Wear
While diamond cutting tools touches the surface of the stone then diamond particles cut stone intermittently during sawing and impact force is generated. This force is more in case of circular blades changed movement direction, which acts on diamond particles constantly [24]. If the impact-shearing stress exceeds the diamond-shearing stress, micro- or macro-fractures occur. The impact mechanism may be the main cause of wear in the cutting operation and it is more while starting the cutting.

5.4. Flush Erosion
During cutting operation flush erosion of the tool is occurred due to flowing action of a fluid stream that carries hard abrasives of tiny rock detritus. Pits, crushed areas, and cracks can form around diamond crystals when hard mineral and rock fragments gain a high velocity and strike the diamond particles [26].

6. Discussion and conclusion
The work presented in this paper examines not only the performance of wear resistant but also the economical cutting tools produced by varying the binder composition of diamond cutting tool composites. By replacing some or all of the cobalt binder with other binder material, a stronger
composite tool results, potentially capable of cutting marble and granite stone significantly higher cutting speeds.

By changing the composition it is possible to process marble and granite stone in better way and improve the cutting ability of the tool. By change of composition cutting tool wear rate in terms of abrasion, fatigue, impact, and flush erosion will be improve. Also use of changed composition (varying the % of binder) in diamond cutting tool improve adhesion and reduce the loosing of diamond particles, other properties of the tool. New tools to be developed for stone cutting improve the probable performance than the conventional cutting tool by 10% in terms of wear rate and tool life.

The fabrication of diamond cutting tool by changing the composition and adding some new material along with cobalt binder (by changing the % of cobalt binder as prices varying) is identified as future work.

References
[1] http://www.mines.rajasthan.gov.in/marble.html
[2] https://flexiblelearning.auckland.ac.nz/rocks_minerals/minerals/hardness.html
[3] Sung, C.M, “Brazed diamond grid: a revolutionary design for diamond saws,” Diamond and Related Materials 8 (1999), 1540–1543
[4] http://www.ibm.gov.in/
[5] http://shodhganga.inflibnet.ac.in/bitstream/10603/30582/12/12_chapter%2005.pdf
[6] Qin S, Jinsheng Z, Wang Z, Heng Z and Jinyan F 2016 Diamond & Related Materials vol.68 pp 143–151
[7] Bouzakis E, Bouzakis K D, Skordaris G, Charalampous P, Kombogiannis S, and Lemmer O, 2014 Diamond and Related Materials Vol. 50 pp77–85
[8] Jani K, Janez K 2009 Strojniški vestnik - Journal of Mechanical Engineering vol.55 pp 775-780
[9] Steven W W 1999 Diamond and Related Materials vol.8 pp 2043–2052
[10] Tonshoff H.K, Hillmann-Apmann H, Asche J, 2002 Diamond and Related Materials vol.11 pp 736–741
[11] Daniel W, Scott L, Michael S, and Daniel N, 2008 Proceedings of the International Conference on Manufacturing Science and Engineering October 7-10, Evanston, Illinois, USA
[12] http://marbleguide.com/news/indian-marble-granite-and-natural-stones-market
[13] Skury A.L.D, Guerold S.B, Márcia GA, and Sergio N.M, 2012 “Materials Science Forum Vols. 727-728 pp 305-309.
[14] Indian Minerals Yearbook 2014 (Part- III: Mineral Reviews) 53rd Edition, Marble (Advance Release) Government of India, Ministry of Mines, Indian Bureau of Mines, NAGPUR
[15] Wang DJ, 1996 J. Cent. South Univ. vol. 3 pp 96-98.
[16] Ersoy A, Atici U, 2004 Diamond Related Material vol.13 pp 22-37.
[17] Aslantas K, Ozbek O, I, and Buyuksags S I 2009 Materials and Manufacturing Processes vol 24:12, pp 1423-1430.
[18] Turchetta S, Sorrentino L, and Bellini A. 2017 Diamond Related Material vol. 71 pp 90-97.
[19] Asche J, Tonshoff H. K, Friemuth 1999 Proc. Diamond Tools Conference 1 pp 151-157.
[20] Dilloio A, Togna A 2003 Int. J. Mach. Tools Manuf. Vol.43 pp 1171-1177.
[21] Sun Q, Zhang J, Wang Z, Fang J 2016 Diamond and Related Materials vol 68 pp 143-151.
[22] Liao Y S, Luo S Y 1992 Wear vol 157 pp 325-337.
[23] Turchetta S 2009 Int. Journal Adv. Manufacturing Technolog vol 44 pp 854-861.
[24] Huang H, Huang G and Xu X 2013 Proc, Inst, NMech, Engg. B J. Engg. Vol 227 pp 943-953.
[25] Carrion L, Polini W and Turchetta S 2003 Diamond and Rekated Materials vol 12 pp 728-732.
[26] Buyuksags I S, Goktan R M 2005 Journal of Material Processing Technology vol 169 pp 258-262.
[27] Nitkiewicz Z, Swierzy M 2006 Journal of Materials Processing Technology vol 175 pp 306-315.