PRACTICAL ASSESSMENT AND IMPROVEMENT OF SUSTAINABILITY IN MARBLE MINING

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Abstract - *The marble extraction process is associated with environmental issues like change in landscape, noise pollution, change in ground water, air pollution, marble slurry can cause land degradation etc. With the ever increasing focus on environment, the mining industry needs to adapt to sustainable mining for better growth and economic development. Marble is mined in Rajsamand (Rajnagar region) by conventional method i.e by wedges with feathers, semi-mechanised method and mechanised method. Morwad, Dharmeta, Arna, Nijharna, Jhanjar are the marble varieties mined in Rajsamand. The sustainability of marble mining operations at Rajsamand, the most productive marble mining area in world has been analysed. A total of 5 different varieties of marble mines were selected and Analytical Hierarchy Process (AHP) is adopted on the basis of key factors of sustainability (technical, economical, safety, social, ecological and rock condition) for selecting the most sustainable mining method. The research demonstrated that conventional mining is least sustainable, resulting in more waste, cracks, irregularly shaped blocks, high working faces, back breaks, rock falls, and accidents. It was concluded and advised that conventional mining methods should be replaced with more sustainable mining methods, namely semi-mechanized mining at the Dharmeta and Jhanjhar marble deposits and mechanised mining at the Morwad, Arna, and Nijharna marble deposits.*

***Key Words*: Sustainability, Marble, Analytical hierarchy process, Varieties, Key factors**

1.INTRODUCTION

Mining is the process of extracting valuable minerals from the earth's crust. It is a metamorphosed limestone created by re-crystallisation under temperature conditions as well as regional metamorphism, according to the geological definition. A sedimentary carbonate rock called marble is created when limestone or dolomite undergoes metamorphism. White is the colour of the most pure calcite (CaCO3) marble. Marble that contains hematite (Fe2O3) is reddish in colour, while marble that contains limonite (FeO (OH) nH2O) is yellow. Marble's green hue is caused by the presence of serpentine (Mg, Fe)3 Si2 O5 (OH).4

When it comes to marble reserves, both in terms of quality and quantity, Rajasthan is the richest state in the nation. Rajasthan has significant reserves of high-quality marble, estimated at 1231 million tonnes (M.T.). Udaipur-Rajsamand, Makrana-Kishangarh, and Banswara-Dungarpur are some of Rajasthan's important marble-occurrence regions.

The largest marble deposits in India is made up by Rajnagar marble occurring around Rajnagar and Kelwa towns in Rajsamand quarter of south- central Rajasthan. Rajsamand marble belongs to late Paleoproterozoic Aravali Supergroup. It is substantially white, coarse-granulated and compact dolomitic marble. Mining is presently being carried out as several, small to medium sized, open sites using conventional and mechanised operations.

The ecology suffers during the extraction of a natural stone. The change in the landscape is probably the most noticeable effect. Quarrying can potentially ruin or displace plant or animal habitats. Even if habitats are not entirely destroyed, quarrying's general environmental disturbance, such as noise pollution, changes to ground or surface water, and ground vibrations, can still have an impact on biodiversity by impairing species' reproductive cycles and causing habitats to dry out or flood. Marble dust, which is produced during the mining process, can harm soil quality, pollute the air, which can have an impact on plant physiology, and taint water sources, making them unfit for human consumption or agricultural use.

In the study "Our Common Future," Brundtland (1987), defined sustainability as the process of meeting existing demands without compromising the capacity of future generations to satisfy their own needs. Enhancing research and development for sustainable manufacturing has become crucial for the industrial sector during the past three decades.

The Analytic Hierarchy Process (AHP) is a system that combines math and psychology to organise and analyse complicated decisions. It consists of three parts: the primary objective or issue you're attempting to resolve, all potential answers, or alternatives, and the standards by which you'll evaluate the options. By putting the decision's criteria and potential outcomes into numerical form and connecting them to the main objective, AHP offers a logical framework for making necessary decision.

2. METHODOLOGY

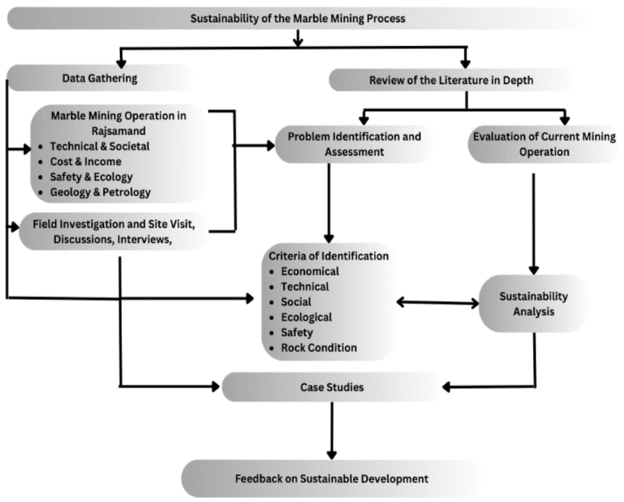

Fig-1: Methodology

The research methodology is presented in Fig. 1. The marble area of Rajsamand was selected for assessing the sustainability of ongoing mining operations. In Rajnagar (Rajsamand), over 50 marble quarries were inspected in order to evaluate the viability of existing mining operations. Both the many types of marble found in Rajsamand and the varied techniques used to mine them were identified. Field visits, site investigations, and group discussions with various stakeholder groups, including lease holders, mining engineers, and supervisors working at various marble quarries in Rajsamand, were used to gather production data, accident records, geological information, meteorological information, lease data, and other information. The sustainability parameters were identified based on the data gathered, and from these the most important parameters for the study were further chosen. These parameters include economic aspects, technical elements, social factors, ecological factors, safety factors, and rock conditions. On the basis of the data collected, sustainability of marble operation was pursued further.

AHP is a tool for supporting multi-criteria decisions. It is typically employed to choose the finest alternative. Six criteria and three options were chosen (Tables 1.1 and 1.2). Using a ranking matrix shown in Table 1.3 and to analyse each criterion's value in relation to others, importance rankings are assigned based on the criteria. As shown in Table 1.4, priorities are determined for each element in the hierarchy, and a normalised matrix is constructed after pair-wise preference comparison.

Table-1: Detail of alternative

S. No.	Criteria	Description
1	Ecn	Economical Factors
2	Tech	Technical Aspects
3	So	Social Factors
4	Eco	Ecological Concerns
5	S	Safety Measures
6	RC	Rock Condition

Table-2: Detail of criteria

S. No.	Alternative	Description
1	MMM	Mechanised Mining Method
2	SMM	Semi Mechanised Mining Method
3	CMM	Conventional Mining Method

Figure 2 shows the hierarchical structure of AHP for choosing the best sustainable marble mining technique. The steps performed are as follows :

1. Identification of the important economical, technical, social, ecological, safety and rock condition sustainability aspects for marble mining operation in Rajnagar (Rajsamand).

2. AHP was used to analyse the main sustainability factors.

3. Three mining methods that are employed in operations to mine dimension stone are identified.

4. Decompose the issue into hierarchy.

5. Quantification of important sustainability elements by comparing their importance to other ones.

Table-3: Fundamental scale of AHP, (Saaty 1980)

Level of Importance	Definition	Interpretation
1	Equally preferred	Two activities contribute equally to the objective
3	Moderately	Experience and judgement slightly favour one activity over another
5	Strongly	Experience and judgement strongly or essentially favour one activity over another
7	Very strongly	An activity is strongly favoured over another and its dominance demonstrated in practice
9	Extremely	The evidence favouring one activity over another is of the highest degree possible for affirmation
2,4,6,8, ...	Intermediate values	Used to represent a compromise between preferences listed above

Table-4: AHPs Pairwise preference comparison and normalised matrix

I	Criteria Scores (Pairwise Preference Comparison)						Normalised Matrix					
	Ecn	Tech	So	Eco	S	RC	Ecn	Tech	So	Eco	S	RC
Ecn	1	1/a	1/b	1/c	1/d	1/e	1/p	1/a X 1/q	1/b X 1/r	1/c X 1/s	1/d X 1/t	1/e X 1/u
Tech	a	1	1/f	1/g	1/h	1/i	a/p	1/q	1/f X 1/r	1/h X 1/s	1/h X 1/t	1/i X 1/u
So	b	f	1	1/j	1/k	1/l	b/p	f/q	1/r	1/j X 1/s	1/k X 1/t	1/l X 1/u
Eco	c	g	j	1	1/m	1/n	c/p	g/q	j/r	1/s	1/m X 1/t	1/n X 1/u
S	d	h	k	m	1	1/o	d/p	h/q	k/r	m/s	1/t	1/o X 1/u
RC	e	i	l	n	o	1	e/p	i/q	l/r	n/s	o/t	1/u
Sum	p	q	r	s	t	u						

6. Utilising the gathered data to create a pair-wise comparison matrix of the sustainability factor based on judgement values.

7. Creating a normalised matrix by dividing each column element's value by the total of that column in the pair-wise comparison matrix that was formed in the previous step.

8. Using the normalised matrix and averaging each element of each row to create the priority matrix.

9. Do a consistency ratio (CR) calculation.In comparison to judgements made only at random, this is used to gauge and examine the consistency of judgements.

10. Quantification of options by comparing relative weights to other options for each factor (criteria). For each alternative—MMM, SMM, and CMM—with respect to each factor, the steps from steps 5th to 8th are repeated. Five matrices of order 3x3 are as a consequence obtained.

11. Figuring out the proportional importance of each choice in relation to each criterion. figuring out how desirable each alternative is.

12. Finding the most sustainable mining technique is the last phase. Calculated by multiplying the priority matrix of elements by the relative weights of the alternatives' factors (Gupta, Jayal, and Jawahir 2010).

2.1 Case Studies

There are numerous types of marble to be found throughout Rajsamand, but especially in Rajnagar. Data was gathered for this project from Rajnagar's marble deposits. As case studies, five distinct marble deposits were chosen. These consist of:

2.2.1 Morwad Marble - Rk Marble

Fig-2 Morwad Marble

In the Rajasthani Rajsamand district of Piplantri, this mine first opened its doors in 1993. It is the biggest open-air white marble mine in the world and has historically produced the most marble. It accounts for around 15% of the nation's total marble production on its own. 10.6 MT of ore have been extracted from the mine thus far. Under shallow marine circumstances, an intricately folded and metamorphosed assemblage formed, primarily made of argillaceous and calcareous facies of rock. This has an off-white, crystalline quality with fine grains and a grey colour stripe as shown in Fig 3.2. The quartz in the marble is smoky.

2.2.2 Dharmeta Marble - Soni Marble

Fig-3 Dharmeta Marble

Dharmeta Marble is a white marble with a light grey or green colour or pattern as shown in above Fig 3.3. It is amazing with its unique design pattern and colour dots. Dharmeta is distinguished by patches of yellow and green. Dolomite and calcite are minerals found in this variety, along with trace amounts of amphibole, quartz, and opaque minerals. The green specks on the stone can be seen more clearly by misting it with water.

2.2.3 Arna Marble - Lovely Marble

Fig-4 Arna Marble

The Arna variety has sporadic green patches and is coarse to medium-grained as shown in above Fig. 3.4. Calcite, dolomite, and amphibole are all present in the Arna variety. It is the type of marble where it is easy to find comparable patterns in large quantities. This type of crystal is fine and has a rough, glazy surface. Because of how closely the design of arna marble resembles that of makrana dungri marble, it is often referred to as semi-dungri marble.

2.2.4 Nijharna Marble - Gomti Marble

Fig-5 Nijharna Marble

White Indian marble stone known as "Nijharna white marble" has distinctive brown swirl pattern decorations all over it. One of the well-known white foundation marbles with brown strikes and a brown colour tone is Nijharna White Marble as shown in above Fig. 3.5. Nijharna is a foliated, fine- to medium-grained marble with a light- to dark-brown centimetre-scale band. It is a siliceous and biotite-partitioned type with medium to coarse grain size.

2.2.5 Jhanjhar Marble - Babu Marble

Fig-6 Jhanjhar Marble

The Aravali supergroup is where the marble resources in Jhanjar are found. Dolomitic marble is found in the local marble resources. Off-white, medium-grained, and crystalline, with greyish or greenish colour lines as shown in Fig. 3.6 above. The layers of the marble contain schist. Jhanjar has discontinuous, light grey, whitish, medium-to-coarse-grained grains. Medium- to coarse-grained black, hazy patches of silica are present.

3 RESULTS AND DISCUSSIONS

The significance of sustainability criteria for each mining alternative was calculated for the five case studies, and the findings are shown in Table 4.1. The criteria with the highest influence and attractiveness value are also highlighted in Table 4.1. The total sustainability analysis for the alternatives is presented in Fig. 4.1 - 4.5. The sustainability analysis of each criterion and the most sustainable mining method associated with each deposit is shown below:

3.1 Economical Factors

The results show that economic variables promote the use of mechanised mining in the Morwad and Nijharna case studies, i.e., 1 and 4, with values of 0.5 and 0.5, respectively. This is mostly due to the market value of marble, and more financial profits can be obtained by using mechanised mining, which produces regular-shaped blocks while producing less waste. However, the economic component, i.e., 2, with a value of 0.65, is more favourable to the use of conventional mining in case study Dharmeta. Because of its low price and strong demand, marble is ideally suited for conventional drilling and blasting technique, which is less expensive and more efficient. Furthermore, case studies Arna and Jhanjhar, i.e., 3 and 5, with economic factor values of 0.5 and 0.5 are more sustainable if mined using the semi-mechanised mining approach. The Arna deposit is made up of fissures, and the rock conditions are unfavourable. The overall cost of mechanised mining of the Jhanjhar deposit is relatively high, and the marble has discontinuous lenses.

3.2 Technical Aspects

In terms of technological factors, it is advised that all marble varieties use mechanised mining methods. This is primarily because the Rajsamand area has an abundance of mines for all of these marble varieties, and in this competitive era, you must have the greatest tools and technologies. The demand for all of these marble variants is great, and the resources are plentiful, making the justification for mechanised mining even stronger. In addition to all of this, mining machinery is now readily accessible for loan, as is technical and trained labour.

3.3 Social Factors

Mechanised mining is the most sustainable mining method based on social aspects in the Morwad and Nijharna case studies, which are 1 and 4, respectively. The highest attractiveness values for both of these deposits are due to the fact that regular-shaped blocks provide more surface rent to locals and have fewer traffic and transportation difficulties. Natural resources are wasted less than with other mining technologies. For the other case studies, Dharmeta, Arna, and Jhanjhar, i.e., 2, 3, and 5, semi-mechanised mining methods are recommended because the people are employed, which immediately improves their living conditions.

3.4 Ecological Concerns

The findings show that mechanised mining has the highest desirability values for the case studies Morwad, Arna, and Nijharna (cases 1, 3, and 4), while semi-mechanised mining is most desirable for the other case studies Dharmeta and Jhanjhar (cases 2 and 5). This is because both mechanised and semi-mechanised mining methods have a lower environmental effect due to the use of advanced mining equipment such as chainsaws, diamond wires, and hydraulic excavators. Similarly, quarry expansion and regular-shaped block extraction generate less waste (less than 20%). As a result, they are the most sustainable in terms of environmental impact. Semi-mechanised mining is recommended slightly more for case studies 2 and 5, because the mining region is more unhabitated.

3.5 Safety Measures

It is one of the most important sustainability qualities, with the highest desirability ratings for mechanised mining in the Morwad, Arna, and Nijharna case studies (1, 3, and 4, respectively). Similarly, greater desirability ratings for semi-mechanised mining are reported in the case studies of Dharmeta and Jhanjhar, i.e., 2 and 5. These desirability values are high due to the convenience and safety of handling mining equipment and machinery.

3.6 Rock Condition

The most sustainable mining method from rock conditions is mechanised mining for the case studies Morwad, Arna, and Nijharna, i.e., 1, 3, and 4. Mechanised mining is preferable for 1, 3, and 4 because if we use the semi-mechanised mining method for these marble varieties, the wastage will increase. Semi-mechanised mining is more favourable for the case studies Dharmeta and Jhanjhar, i.e., 2 and 5, due to the rock consisting of fissures and cracks.

Table-5: Overall desirability values of major sustainability parameters across all case studies.

Criteria	Case I Morwad			Case II Dharmeta			Case III Arna			Case IV Nijharna			Case V Jhanjhar		
	MM	SM	CM	MM	SM	CM	MM	SM	CM	MM	SM	CM	MM	SM	CM
Economical	0.5	0.4	0.1	0.13	0.217	0.652	0.4	0.5	0.1	0.5	0.417	0.083	0.375	0.5	0.125
Technical	0.5	0.4	0.1	0.5	0.375	0.125	0.5	0.4	0.1	0.545	0.364	0.091	0.5	0.375	0.125
Social	0.556	0.333	0.111	0.333	0.556	0.111	0.375	0.5	0.125	0.5	0.4	0.1	0.333	0.5	0.167
Ecological	0.444	0.444	0.111	0.333	0.556	0.111	0.444	0.444	0.111	0.556	0.333	0.111	0.4	0.5	0.1
Safety	0.5	0.375	0.125	0.375	0.5	0.125	0.5	0.375	0.125	0.556	0.333	0.111	0.375	0.5	0.125
Rock condition	0.5	0.333	0.167	0.333	0.5	0.167	0.429	0.429	0.143	0.5	0.333	0.167	0.333	0.5	0.167
Desirability Value	**0.5**	0.387	0.113	0.331	**0.488**	0.181	**0.444**	0.437	0.12	**0.542**	0.355	0.103	0.375	**0.496**	0.13
Most Sustainable Mining Method	Mechanized Mining			Semi Mechanized Mining			Mechanized Mining			Mechanized Mining			Semi Mechanized Mining		

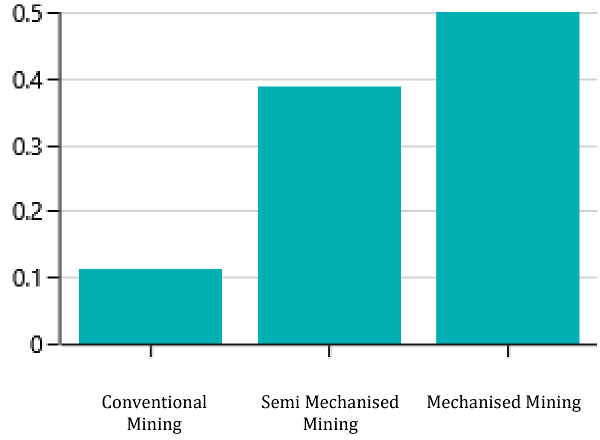

Fig-6: Morwad sustainability analysis

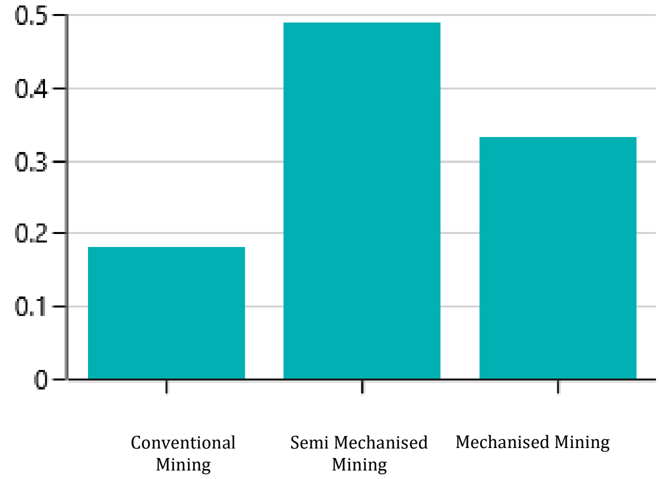

Fig-7: Dharmeta sustainability analysis

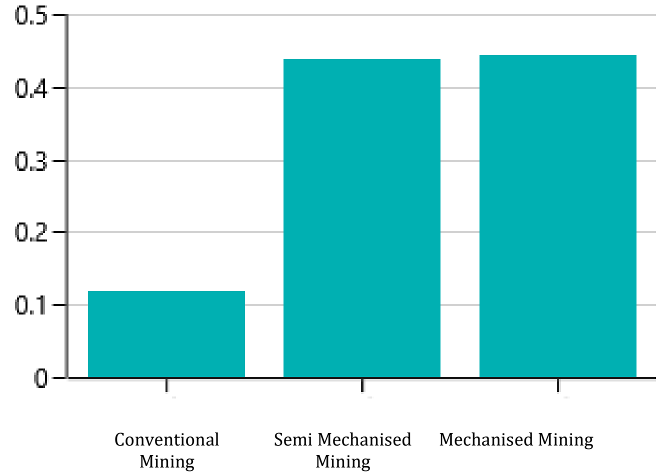

Fig-8: Arna sustainability analysis

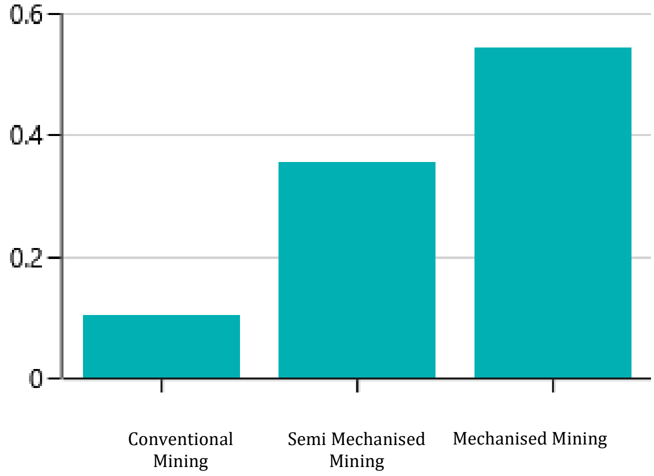

Fig-9 Nijharna sustainability analysis

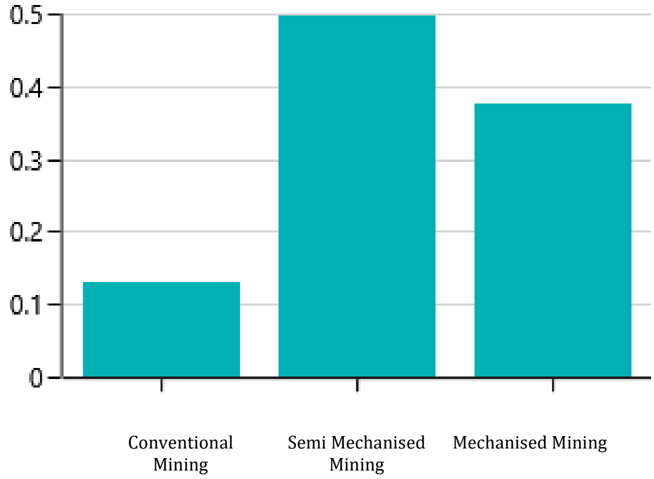

Fig-10 Jhanjhar sustainability analysis

4. CONCLUSIONS

This research examines the overall sustainability of marble variants in Rajsamand using case studies. According to the findings, mechanised mining (rope cutting) is the most sustainable option in the case studies. Morwad, Arna, and Nijharna, while semi-mechanised mining (expansion material) is more viable for case studies in Dharmeta and Jhanjhar.

Conventional mining is unsustainable for any of the deposits because to increased mining and processing losses, despite decreased mining costs. Uncontrolled blasting in traditional mining can cause micro- and macro-cracks in both blasted and unblasted rock formations. Furthermore, conventional mining methods cannot produce regular or geometric blocks, which is the method's fundamental shortcoming. Traditional mining practices raise health and environmental concerns, and they are also hazardous to workers and inhabitants of mining communities. Furthermore, developing a benching system using this method is extremely difficult, and it should be replaced with semi-mechanised mining.

This methodology was validated by deploying it in selected marble mines ranked from low to high. It was determined to be useful and simple to apply, and it has the potential to improve the mining industry's sustainability practices.

Trainings, seminars, and campaigns should be held on a regular basis to educate and acquaint mining stakeholders about sustainable development and its benefits.

Future research studies can consider additional elements such as climate, infrastructure, location, accessibility, and mine closure.

ACKNOWLEDGEMENT

I take it to be proud privilege to avail this opportunity to express my sincere and deep sense of gratitude to my major advisor Dr. S.C. Jain, Professor, Department of Mining Engineering, College of Technology and Engineering, MPUAT, Udaipur for this stimulating guidance, constructive suggestion, keen and sustained interest and incessant encouragement bestowed during the entire period of investigation, as well as critically going through the manuscript.

I am gratified to record sincere thanks to the member of the advisory committee Dr. Anupam Bhatnagar, Professor & Head, Department of Mining Engineering, CTAE, Udaipur; Dr. Narayan Lal Panwar, Associate Professor, Department of Mechanical Engineering, CTAE, Udaipur; Dr. Chitranjan Agarwal, DRI Nominee and Associate Professor, Department of Mechanical Engineering, CTAE, Udaipur for this generous gestures and valuable suggestion in planning and execution of this study.

With respect and deep sense of gratitude, I hereby express my thank to Dr. P.K. Singh, Dean, College of Technology and Engineering, Udaipur for providing necessary facilities to carry out my work.

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