Reusing marble and granite dust as cement replacement in cementitious composites: a review on sustainability benefits and critical challenges

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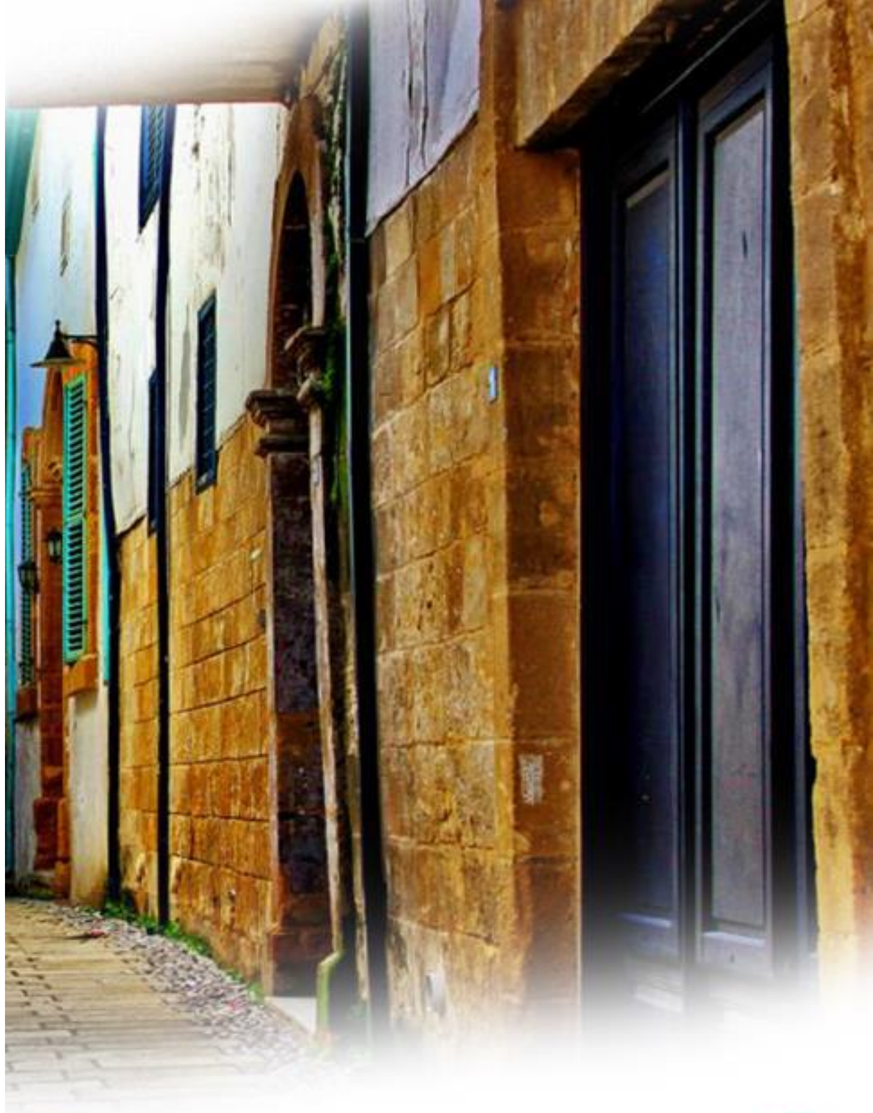
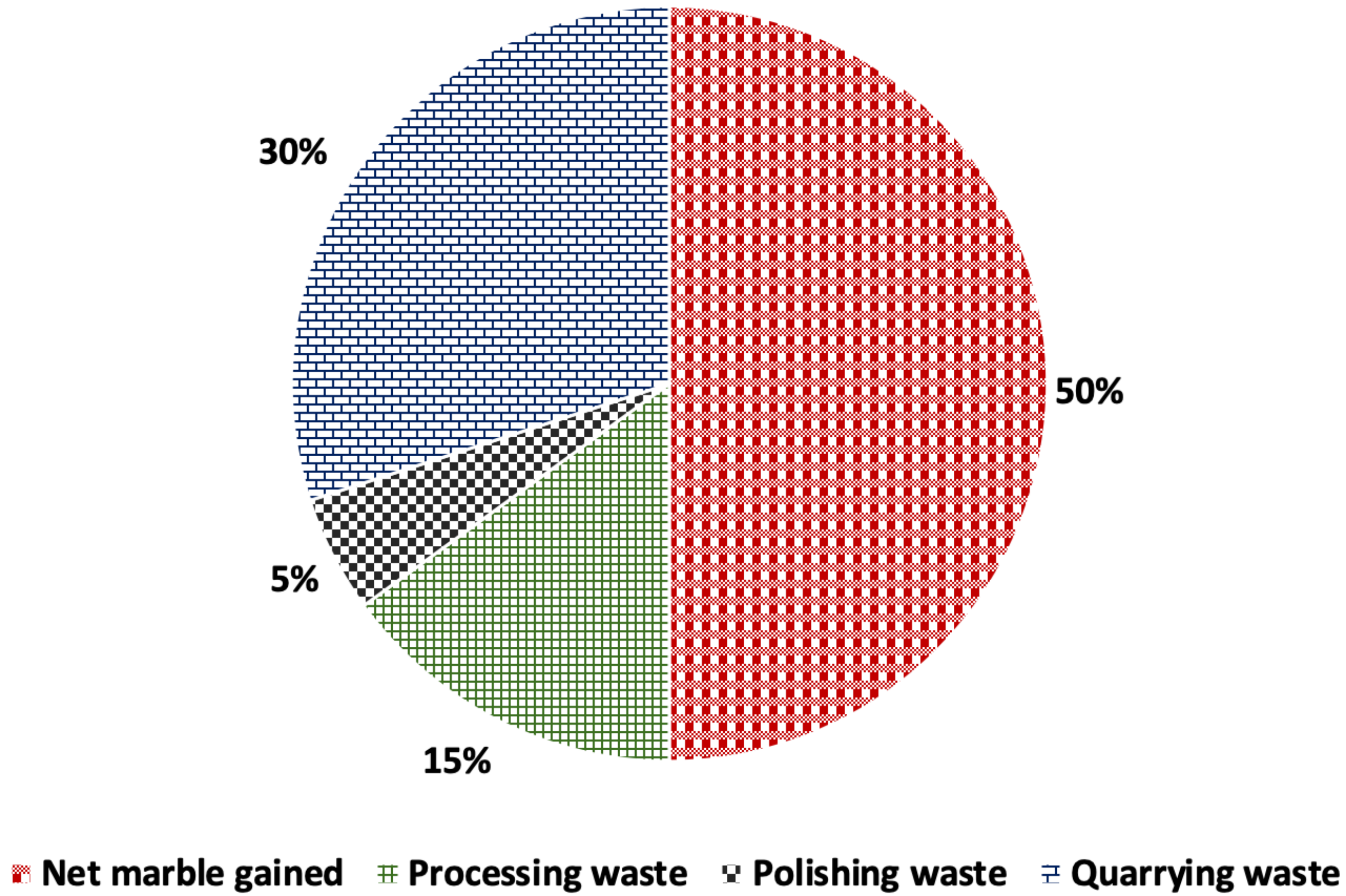


Introduction

- For the past two decades, substantial increase in the stone consumption is observed worldwide which can be attributed to the rapid rise in population and economic growth.
- Several types of stone such as marble, limestone, granite, shale, etc. are used in construction industry.
- Nowadays, various operations on stones such as quarrying, cutting and sawing etc. are being done by modern techniques which are continuously enhancing the stone production rate along with stone waste.
- Due to excessive stone processing operations, stone waste has now become a critical environmental problem and a threat to modern civilization.

Introduction



Introduction

- Like MD, GD is also a by-product produced during processing (cutting and grinding) of granite stone.
- According to an estimate, approximately 65% of waste is produced during different industrial processes on granite stone.
- Like MD, GD causes environmental problems like air/water pollution, land infertility and spoiling natural beauty.

Introduction

- Parallel to this, after Group of Eight (G8) summit regarding attainment of sustainability goals, construction materials especially Ordinary Portland Cement (OPC) is under heavy inspection.
- This inspection is the main reason for the rapid use of supplementary cementitious materials (SCMs) as OPC replacement, such as fly ash, silica fume, rice husk ash (RHA), ground granulated blast-furnace slag (GGBS), limestone, MD, GD.
- Replacing a large amount of OPC by SCMs is the most promising strategy that largely contributes to reduce the usage of cementitious clinker, which ultimately improves environmental footprint.
- Environmental and energy issues like carbon dioxide (CO_2) emissions, energy usage, depletion of natural resources, and others, influenced the replacement of OPC with SCMs .
- In view of this, several researchers showed keen interest in using MD and GD as cement replacement preparing cementitious materials.
- Researchers believe that increased usability of MD and GD will pose several benefits on stone and construction industries such as a reduction in disposal cost (or landfill site cost), promotion of greener environment, enhancement of properties of cementitious composites, and preferment in sustainability development.

Chemical properties of MD/GD

- Since the past decade, plenty of researches were conducted on using marble and granite as cement replacement, aggregate replacement, filler for self-compacting concrete, soil stabilization, brick and tiles manufacturing.
- The studies revealed that the chemical composition of MD have greater lime and magnesium concentration while GD have greater quantity of silica and alumina.

Rheological properties

- With the inclusion of both MD/GD, the workability of the mixtures almost always decreases.
- Especially high water consumption is required when including stone particles smaller than 75 µm.
- The increase in water demand of all cement composites containing marble slurry may be due to the higher surface area of MD (0.67 m2 / g) compared to the surface area of cement (0.32 m2 / g), which led to an increase in the need for water.

Rheological properties

- The initial setting time of paste mixtures containing 10% and 50% MD was 32% and 119%, respectively, which was higher than that of the control cement paste.
- On the other hand, the final setting time of the mixture containing 10% and 50% MD was 9% and 62%, respectively, longer.
- An increase in the final setting time of a mixture containing MD indicates a delay in the hydration process

MT[a]	CC type	Replacement level (%)	Workability	Suggested replacement (%)	RF[b]
MD	Mortar	0%, 8%	Decreased	8%	[44]
MD	Cement	0%, 10%	Decreased	10%	[29]
MD	Mortar and concrete	0%, 10%, 20%	Decreased	10%	[45]
MD	Concrete	0%, 5%, 7.5%, 10%	Decreased	7.5%	[30]
MD	Concrete	0%, 5%, 10%, 15%, 20%	Decreased	10%	[46]
MD	Concrete	0%, 5%, 10%, 15%, 20%	Decreased	10%	[47]
MD	Mortar	0, 5, 10, 15, 20, 30, 50	Decreased	30	[48]
MD	Concrete	0, 5, 10, 15	Decreased	10	[49]
MD	Concrete	0, 2.5, 5, 7.5, 10	Decreased	10	[50]
MD	Concrete	0, 5, 10, 15, 20	Decreased	10	[51]
MD	Concrete	0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20	Increased	10	[52]
MD	High-performance concrete	0, 2.5, 5, 7.5, 10, 12.5, 15	Decreased	10	[53]
MD	Concrete	0, 5, 10, 15, 20	Decreased	10	[54]
MD	Concrete	0, 5, 7.5, 10, 15	Decreased	10	[12]
MD	Concrete	0, 5, 10, 15, 20, 25	Decreased	10	[55]
MD	Concrete	0, 5, 10, 15, 20, 25	Decreased	10	[56]
MD	High-performance concrete	0, 15	Decreased	15	[57]
MD	Concrete	0, 5, 10, 20	No change	10	[25]
MD	Mortar	0, 10, 20, 30, 40	Decreased	20	[26]
MD	Mortar	0, 10, 20, 30, 40, 50	Decreased	10	[42]
MD	Concrete	5,10,15,20,25	Decreased	10	[56]
GD	SCC	20,30,40,50	Increased	50	[17]
GD	Concrete	5,10,20	Decreased	10	[14]
GD	Mortar	5,10	Decreased	10	[36]
GD	Mortar and concrete	10,20,30,40	Decreased	20	[58]
GD	Concrete	5,10,20	Decreased	10	[11]
GD	Mortar	5,10,15	Decreased	10	[41]
GD	Concrete	20,30,40,50	Increased	40	[9]
GD	mortar	5,10,15	Decreased	10	[13]
GD	Mortar	30,40	Decreased	30	[43]

Mechanical properties

- Researchers have mixed reviews regarding the effect of MD and GD as cement replacement on mechanical properties (such as compressive, flexural and tensile strength) of CC.
- For example, some researchers believe that incorporation of MD/GD as cement replacement in CC decreases mechanical properties (especially compressive strength) while some reported increase in mechanical properties

Mechanical properties

The decrease in mechanical properties of MD/GD modified CC which can be attributed to the following reasons:

1. The reduction in the strength building constituents of cement (or cementing materials) like dicalcium silicate (C2S) and tricalcium silicate (C3S), caused by adding MD/GD. This phenomena is called dilution of pozzolanic reactions.
2. MD/GD comes in contact with water to get agglomerated leading to a discontinuous media and reduction in compressive strength.
3. If the particles of MD/GD are greater than cement, it leads to greater number of voids in the matrix of MD/GD modified composites as compared to pure CC.
4. Although MD/GD sometimes contains comparable or even high amount of silica as compared to other SCMs (like fly ash, GGBS etc.),their reactivity is still lower
5. If the particle size of MD/GD is smaller than cement, it leads to higher water absorption due to higher specific areas, which reduces the amount of water available for hydration. However, superplasticizer can be utilized to counter this deficiency

Mechanical properties

The increase in mechanical properties of MD/GD modified CC can be attributed to the following reasons:

1. If MD/GD containing sufficient silica reacts with calcium hydroxide provided the hydration of cement leading to additional binding phase due to pozzolanic properties.
2. Cement containing tricalcium aluminate (C_3A) and MD/GD containing calcium carbonate react with each other to form calcium carboaluminate which increases hydration speed of cement.
3. The very fine particle size of MD/GD provide pore filling effect which increases the properties (such as density) of interfacial transition zone (ITZ) product surrounding aggregates . This pore filling effect of MD/GD also provide adequate nucleus for hydration

Mechanical properties

- In summary, the addition of MD/GD as cement replacement in CC can be both detrimental and effective for the mechanical properties of CC depending upon various factors of MD/GD used. These factors include particle size of MD/GD, addition of other SCMs, water to binder ratio, addition of superplasticizer, and source of MD/GD.
- However, the decrease in mechanical properties of MD/GD modified CC can be compensated by addition of other SCMs (like fly ash, silica fume and GGBS, etc.).

Durability properties

- Most of the researchers reported that incorporation of MD/GD improved the durability properties of CC.
- By evaluating various researches with approximately same parameters, it can be concluded that GD outperformed MD against durability properties.

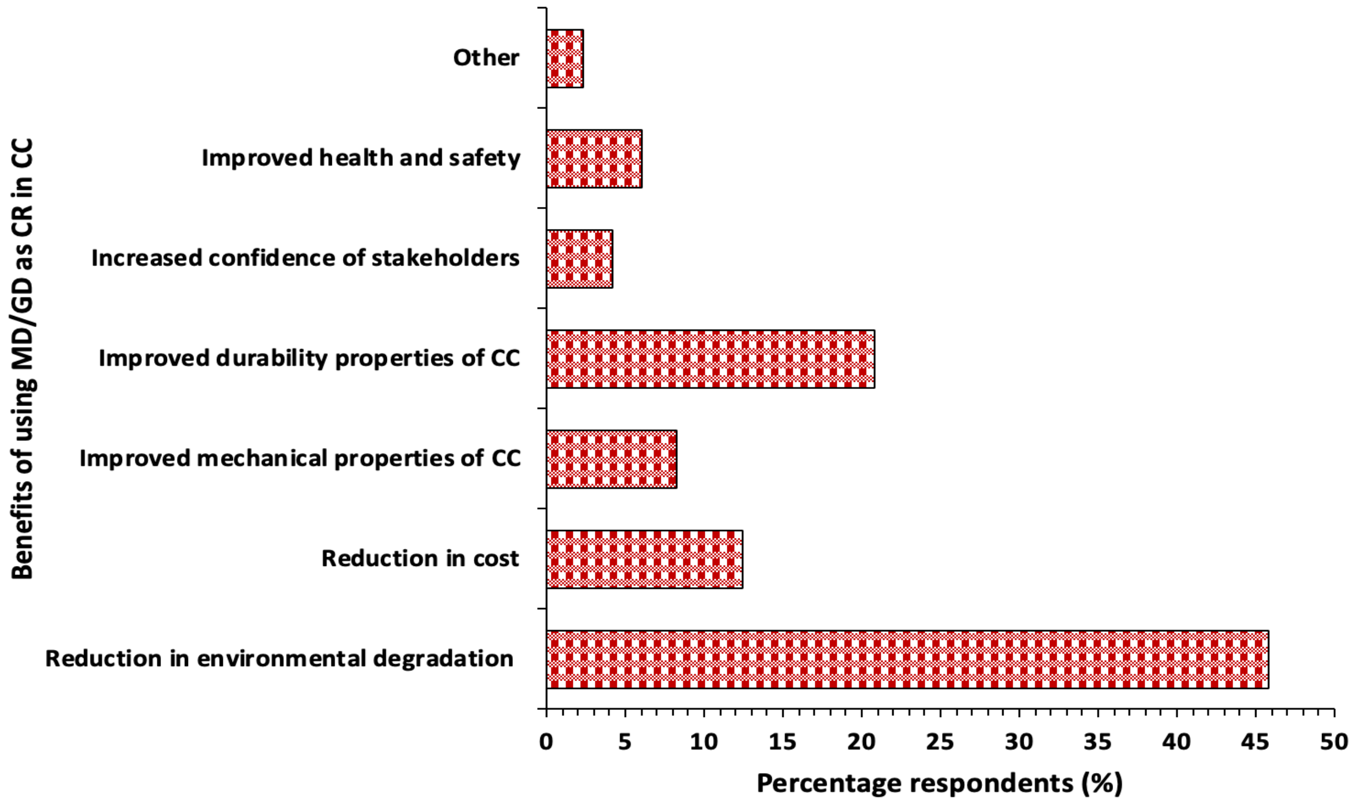
MT[a]	CC type	Replacement level (%)	Durability properties	Effect	Optimum replacement (%)	RF[b]
MD	Concrete	0, 5, 7.5, 10	Carbonation	Equal to control sample	7.5	[30]
MD	Concrete	0, 5, 10, 15, 20, 30, 50	Water Absorption	Decreased	30	[8]
MD	Concrete	0, 5, 10, 15, 20	Water Absorption	Decreased	10	[54]
			UPV	Increased		
MD	Mortar	0, 5, 10, 15, 20, 25	Water Absorption	Decreased	10	[16]
			UPV	Increased		
			Carbonation	Increased		
MD	Concrete	0, 5, 10, 15, 20, 25	Water Absorption	Decreased	10	[17]
MD	Concrete	0, 10, 20, 30, 40	Water Absorption	Increased above 20	20	[14]
			Abrasion resistance	Increased		
MD	Concrete	0, 5, 10, 20	Water Absorption	Decreased	10	[25]
			UPV	Decreased		
			Carbonation	Increased		
MD	Concrete	0, 5,10,15,20,25	Permeability	Decreased	10	[56]
			Chloride diffusion	Decreased		
MD	SCC	0, 20,30,40,50	Water Absorption	Decreased	20	[17]
			Sulphate attack resistance	Increased		
GD	Concrete	0, 5,10,20	Sulphate attack resistance	Increased	10	[14]
			Water Absorption	Decreased	5	
GD	Mortar and Concrete	0, 40	Water absorption	Decreased	20	[58]
			Abrasion resistance	Decreased		
			Freeze and thaw resistance	Decreased		
GD	Mortar	0, 5,10	Alkali silica reaction prevention	Increased	10	[36]
			Chloride ion diffusion	Decreased		
GD	Mortar and concrete	0, 10,20,30,40	Freeze-thaw resistance	Increased	20	[58]
			Abrasion resistance	Increased		
			Acid attack resistance	Increased		
GD	SCC	0, 20,30,40,50	Water Absorption	Decreased	30	[17]
			Sulphate attack resistance	Increased		
GD	Concrete	0, 5,10,20	Water absorption	No effect	10	[11]

Sustainability assessment and incurring challenges of MD/GD cementitious composites

- In order to evaluate the capability of MD/GD as cement replacement to promote sustainability in construction industry and counter challenges of using MD/GD in cementitious composites, 100 responses were collected from different researchers worldwide.
- The researchers selected for this questionnaire had an experience in working on MD/GD or any other SCMs.
- In addition, the countries selected for this practice included developed, developing, MD/GD resource rich and resource deficient countries. Countries included in this survey are the United States, Australia, Belgium. Germany, France, Finland, India, Pakistan, Turkey, Russia, Hong Kong, China, Japan, Brazil, Egypt and Iran.

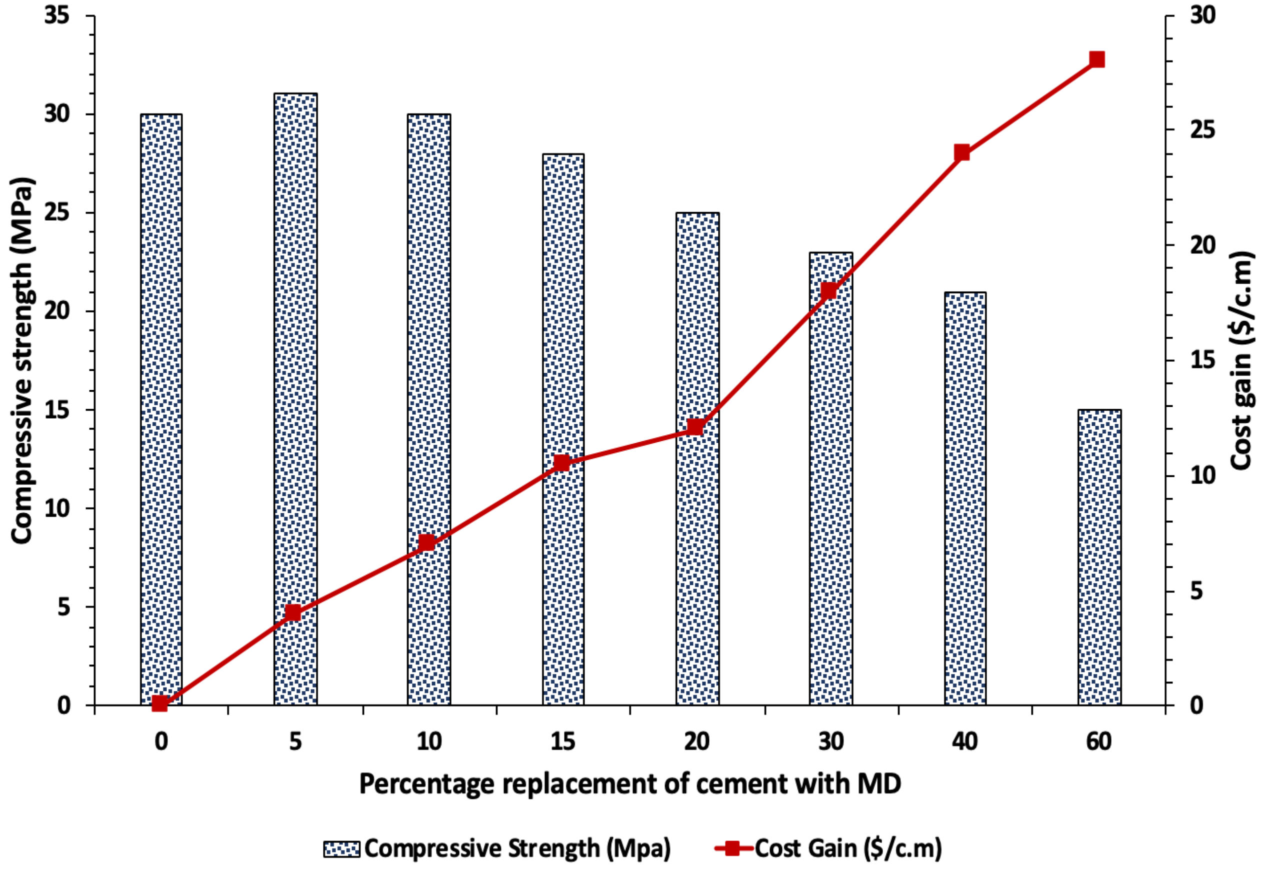
Environmental aspect

- The participating researchers were asked to identify the main benefit of incorporating MD/GD as cement replacement in CC



Economical aspect

- An analysis of cost-compressive strength of grade M30 produced by replacing cement with MD (0-60%) were done .
- It showed that replacing 5-10% cement with MD can reduce cost by 4-8 USD/m^3
- As granite being less expensive than marble (in both resource rich and deficient country), incorporation of 5-15% GD as cement replacement will further reduce the cost.

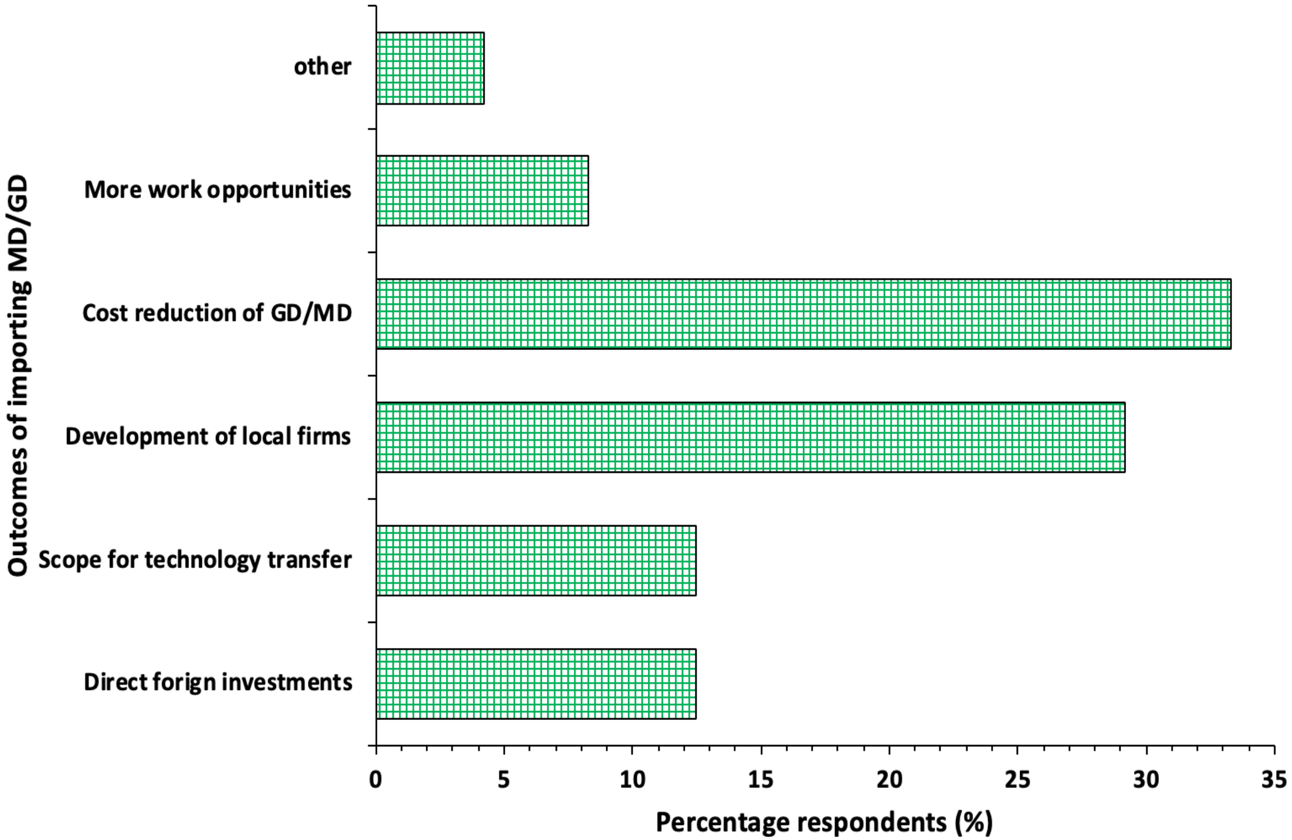


Social aspect

- This aspect of sustainability includes various parameters (related to this topic) for well-being of society i-e health improvement, job opportunities, and good working environment etc.
- As the MD/GD gets airborne which causes different health problems like asthma, flu, and various lung diseases. However, the usability of MD/GD as cement replacement in CC reduces the rate of mentioned diseases.
- In addition, the replacement of cement with MD/GD will also decrease cement production leading to reduced air pollution. Apart from health improvement, the usability of MD/GD in CC can also improve other aspect of society/country.

Social aspect

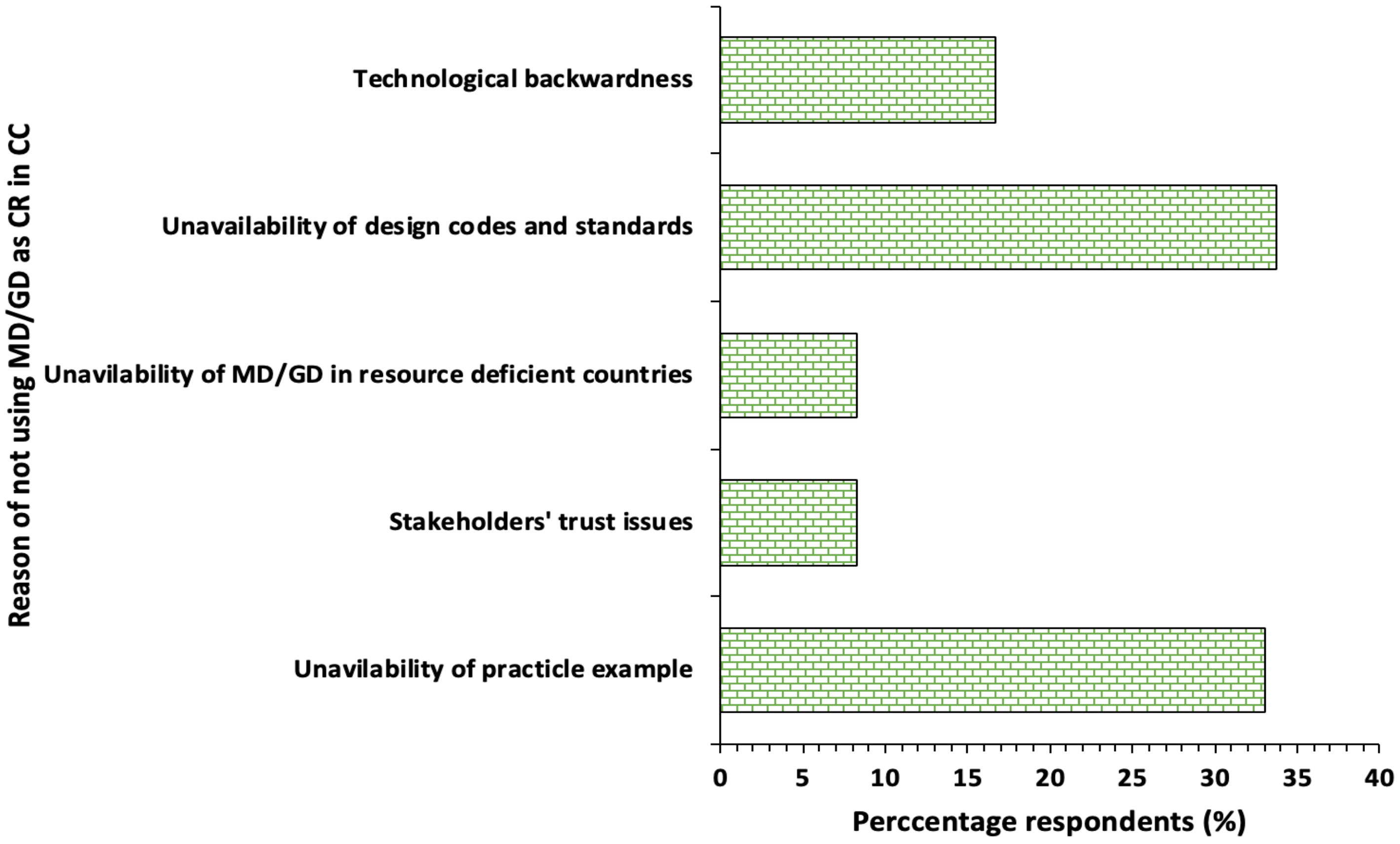
- The research participants were asked to select one important outcome/benefit of importing MD/GD, and the answers received were in the favour of society's/country's (both importing and exporting) growth.
- According to participating researchers, importing MD/GD can reduce their cost due to increase in competition (34 votes), which can only happen by effectively promoting MD/GD as cement replacement materials in preparing CC.



Challenges

- Despite of humongous laboratory research and statistical analysis data representing potential of using MD/GD as cement replacement to improve mechanical properties (mostly with other SCMs), enhance durability properties of CC, along with appreciable reduction in environmental degradation and cost, practical use of MD/GD in CC is still restricted.
- The prime factors responsible for this restriction include uncertain specifications/properties, risk and cost.

Challenges


Technological backwardness
Unavailability of design codes and standards
Unavilability of MD/GD in resource deficient countries
Stakeholders' trust issues
Unavilability of practicle example
Reason of not using MD/GD as CR in CC
0
5
10
15
20
25
30
35
40
Perccentage respondents (%)

Challenges

Furthermore, some other reasons for not incorporating MD/GD as cement replacement in producing CC are summarized below:

1. There is no specific procedure to store and handle MD/GD. As MD/GD are very fine and water absorbent, they can easily get moist and hard and become unfit to use as cement replacement material
2. Most of the developing countries do not care about the environmental degradation due to production and consumption of cement. Such countries should be encouraged to use MD/GD as cement replacement because construction rate in such countries is very high as it is believed that infrastructure of a country is symbol of its economic growth and well-being

Conclusions

Following deductions can be made by above discussion:

1. Workability of MD/GD modified CC decreases which can attributed to the high-water absorption, high specific area and dense packing of MD/GD as compared to cement. However, reduced workability can be compensated by the addition of superplasticizer
2. Addition of MD/GD alone as cement replacement can lead to reduced mechanical of CC due to dilution of pozzolanic reactions, agglomeration, large number of voids and reduced amount of water needed for hydration reaction. However, GD performs better than MD because GD has both filler effect and pozzolanic reactivity, but MD only provide filler effect. The reduced strength of MD/GD modified CC can be compensated by addition of other SCMs (such as fly ash, silica fume and nano-silica) which can be ascribed to the formation of calcium carboaluminate and filler effect
3. Almost all published literature suggests that incorporation of MD/GD as cement replacement in CC increases durability properties (like carbonation, sulphate attack, chloride migration, and alkali silica reaction) which can be attributed to the formation of pore volume CC (due to addition of MD/GD). Like mechanical properties, GD also performed better in increasing durability properties of CC as compared to MD
4. LCA analysis (in published literature) of incorporation of MD/GD revealed reduction in environmental degradation and cost, which is similar to the responses of researchers). The incorporation of 5-10% MD can reduce the production cost of CC up to 10 USD/c.m. However, usability of MD/GD in resource deficient could increase the cost of CC production but it can be justified by environmental sustainability as recommended by participating researchers.
5. Instead of several advantages of using MD/GD as cement replacement, there are various challenges to promote their usability at commercial level. In view of this, participating researchers has suggested various strategies such as addressing shortcomings in MD/GD, formulation of design codes and standards for MD/GD and construction of real-life infrastructure by incorporating MD/GD. All these strategies will improve the position of MD/GD among stakeholder.

Recommendations

The usability of MD/GD can be promoted by addressing following gaps in research:

1. The compatibility of MD/GD to be used in high-performance CC should be checked and analysed because almost all the published literature is available on MD/GD modified conventional or self-compacting CC
2. Properties like abrasion resistance should further researched as the previously published works show inconclusiveness. However, if MD/GD incorporation detrimentally effects CC, then alternative solutions to encounter this problem should be searched for.
3. Cost effective methods of increasing workability of MD/GD modified CC should be analysed. However, these methods must not affect other properties of CC.

Thanks for your attention