A New Method of Utilization of Mining Waste as an Aggregate

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Abstract: The quantities of waste rocks and tailings generated from the limestone mines have increased in the last decades. The accumulation and surface storage of these mine wastes represents a real challenge in terms of environmental and sustainability point of view for the cement industry. Thus, the recycling and valorization of these mine wastes is one of the most effective ways of reducing their volume and mitigating their negative environmental impact. In India, most of the cement plants are operating on heterogeneous intricate limestone deposits with the result that mine reject generation is high. Besides low grade its variability is extremely high due to the intercalation of dolomite, clay, pegmatite, schist, etc. Recently, the Indian Bureau of Mines issued a notification for implementation for thresh hold value of minerals. "Threshold Value of Minerals" means the limit prescribed by the Indian Bureau of Mines based on the chemical composition of Limestone. The limestone having CaO 34% (Min.) and MgO 5% (Max) are incorporated as beneficiable/marketable, below which a mineral/material obtained after mining can be discarded as waste. As per IBM policy, around 7000 Million tons of waste material are generated throughout the cement industry. The aim and objective of this paper is to study the suitability of mining waste i.e. dolomitic - limestone as an aggregate for the ready mixed concrete and road construction by focusing mainly on the mechanical and chemical performance of each types of waste.
Keywords: Dolomite, Limestone, Aggregate.

Introduction

Limestone is the basic raw material for cement manufacture, and the growth of the cement industry depends on the availability of cement grade limestone. India has huge limestone deposits distributed throughout the geological stratigraphic horizons, starting from Archaean to Tertiary formations. The quality variation of limestone from deposit to deposit is very wide in India. The geographical distribution of limestone deposits in India is also not uniform. Some states do not have any limestone deposits. In India, limestone is basically a sedimentary rock composed mainly of calcium carbonate ($CaCO_3$) in the form of calcite with secondary minerals like quartz, feldspar, mica, and clay present as accessories. About 90% of the Indian limestones are of sedimentary origin, and the other10% are of partial metamorphic origin. The two most important constituents of limestone are calcite and dolomite (2). Magnesium carbonate is commonly found in limestone, either as dolomite ($CaMg(CO_3)_2$) or as magnesite ($MgCO_3$) mixed with calcite. Such rocks are termed dolomitic or magnesian limestone. Limestone is altered by dynamic or contact metamorphism to become coarsely crystalline and is referred to as marble or crystalline limestone. The limestone that is used by the cement industry is a bedded limestone deposit intercalated with various sedimentary and metamorphic rocks like dolomite, amphibolites, pegmatite, basalt, shale, and phyllite, which are not used during the cement manufacturing process. As per the Indian Bureau of Mines guidelines, the rejection ratio of minerals is more in the limestone mine with respect to the threshold value. Around 6000–7000 MT of reject grade limestone present throughout the cement industry are presently not in use.

Fig. 1-2. Reject Grade Limestone after mining.

Sampling
To ensure representative sampling, samples were collected from 10-12 different locations, including one of mine located in the North region. The quantity of reject grade samples collected from each location was about 300 kg. The quantity was reduced to about 100 kg by coning and quartering, and the same was used for evaluation. Three sets of representative samples (OB1, OB2, and OB3) have been prepared for comparison purposes. Coarse aggregates of 10 and 20 mm nominal size were prepared by crushing the overburden samples both in the laboratory and in a commercial jaw crusher. The crushed aggregates were evaluated for various characteristics as per the requirements of IS 383–2016 (Indian Standard–Specifications for Coarse and Fine Aggregates for Concrete).

Preparation of Coarse Aggregates from Reject Grade Limestone
Lab Scale
Around 500 kg. of 10 and 20 mm aggregate have been prepared using a laboratory jaw crusher for complete physical, chemical, and mechanical analysis. A representative image is given below.


Fig. 3-4. 10 & 20 mm aggregate preparation at Lab scale.

Commercial Production
After chemical and mechanical evaluation of laboratory produced aggregate, around 5 tons of coarse aggregate have been produced using a commercial scale jaw crusher having a capacity of 500 tons /day. The operational parameters of jaw crusher have been optimized to achieve good-quality coarse aggregates that can meet the requirements of IS 383 -2016.


Fig. 5-6. 10 & 20 mm aggregate preparation at commercial scale.

Quality of Aggregate
The aggregates were prepared from overburden are hard, compact and dense and are free from veins and adherent coatings. The uncrushed stone samples as well as the crushed aggregates prepared from these were free from disintegrated pieces and vegetable matter.

Physical Properties

The specific gravity, bulk density, and water absorption of crushed aggregates were tested in accordance with the method specified in IS: 2386 (Part III)- 1963, and the results are given in Table 1. The specific gravity for all three aggregate samples was in the range of 2.35-2.56 and is considered normal for aggregates for use in concrete. The values were in a close range indicating consistency in the specific gravity of the aggregates prepared from the overburden limestone. The bulk density for all three aggregate samples was in the close range of 1.39 – 1.56 kg/l indicating consistency in bulk density. The water absorption for all three aggregate samples was in the range of 3.5 – 5.26 % and is considered marginally high for crushed aggregates for use in cement concrete. There are no limits specified in IS 383-2016 for water absorption value. However, the value is required to be reported.

Table 1. Sp. Gravity, BD, & Water Absorption of 10 & 20 mm nominal size Aggregate.

Parameters	**OB1**		**OB2**		**OB3**	
	10 mm	**20 mm**	**10 mm**	**20 mm**	**10 mm**	**20 mm**
Sp. Gravity	2.55	2.5	2.48	2.56	2.35	2.4
Bulk Density (Kg/l)	1.41	1.39	1.48	1.42	1.5	1.56
Water Absorption (%)	5.26	3.52	4.7	2.95	5.1	3.2

Mechanical Properties

The flakiness index and elongation index of crushed aggregates were tested in accordance with the method specified in IS:2386 (Part I) – 1963 and the results are given in Table 2. The flakiness index of an aggregate is the percentage by weight of particles in it whose least dimension (thickness) is less than three-fifths of their mean dimension. The flakiness index of the crushed aggregates was in the range of 32.45–35.0 for 20mm and 49.8–50.6 for 10 mm, and the elongation index of 10 mm ranges from 16.4-19.2, and that of 20mm varies from 14.5- 21.5. The maximum limit is 40% for the wearing surface mentioned in the standard.

The crushing value, impact value, and abrasion value of crushed aggregates was tested in accordance with the method specified in IS:2386 (Part IV) -1963, and the results are given in Table 2. The aggregate crushing value for all three samples was in the range of 18.17 -20.36% for 20 mm and 29.9–31.97 for 10 mm, impact value was in the range of 18.65-25.20 % for 20 mm and 28.56 -31.97 for 10mm and the abrasion value was in the range of 45.8 -48.9 % for 20 mm and 51.4 – 55.5% for 10 mm. All the 20 mm aggregate samples met the requirement of BIS, i.e., maximum crushing, impact, and abrasion values are 30 % for aggregates to be used in concrete for wearing surfaces such as runways, roads, and pavements and a maximum of 50 % (IS 383- 2016) for aggregates to be used on non-wearing surfaces.

Table 2. Mechanical Properties of 10 & 20 mm nominal aggregate.

Parameters	**OB1**		**OB2**		**OB3**	
	10 mm	**20 mm**	**10 mm**	**20 mm**	**10 mm**	**20 mm**
Flakiness Index	50.65	35	51.2	32.45	49.83	33.45
Elongation Index	17.8	14.5	19.2	21.5	16.4	18.5
Crushing Value	31.97	18.17	30.76	19.2	29.9	20.36
Impact Value	31.97	25.2	32.3	18.65	28.56	19.56
Abrasion Value	55.5	48.9	52.3	47.87	51.43	45.8

Presence of Deleterious Material

The crushed aggregate samples were tested for the presence of deleterious materials as per the requirements of IS 383-2016 following the methods specified in IS:2386 (Part I and Part II)- 1963. The results are given in Table 3. For crushed coarse aggregates, IS 383 limits the content of material finer than 75 microns to a maximum of 3 %, clay lumps (max 1%), coal and lignite (max 1%), and deleterious material (max 5%). All three aggregate samples prepared from overburden stone contained material finer than 75 microns in the range of 0.31-0.75% (Table 3), clay lumps in the range of 0.20-0.40%, coal and lignite (0.050-0.080%), and deleterious materials in the range of 0.3-0.98%, indicating that all three samples met the requirements on the maximum limit as per BIS requirements with a comfortable margin.

Table 3. Deleterious Material present in the crushed aggregates (Wt%).

Parameters	OB1	OB2	OB3
Coal & Lignite	< 0.050	<0.080	<0.060
Clay Lumps	<0.20	<0.40	<0.38
Material finer than 75 µm	0.31	0.62	0.75
Total Deleterious material	0.31	0.98	0.76

Alkali Aggregate Reactivity & Soundness

The potential alkali-aggregate reactivity of crushed aggregate samples prepared from overburden rock was tested in accordance with the chemical method specified in IS:2386 (Part VII)- 1963. The aggregate samples were crushed to obtain the size fraction passing 300 µm and being retained at 150 µm. Three test portions of 25 g each for each aggregate sample were reacted with 25 ml of a 1 N caustic soda (NaOH) solution for 24 hours in sealed containers at 80˚C. After the reaction period of 24 hours, the aggregate residue was filtered from the solution, and the filtrate was used to determine the dissolved silica and reduction in alkalinity. The reduction in alkalinity and dissolved silica content in the crushed aggregate sample is 217.12 millimoles/ litre and 3.33 millimoles/litre indicates alkali-aggregate reactivity is innocuous and meets the requirements as per BIS with a comfortable margin. The coarse aggregate samples were subjected to five cycles of accelerated soundness testing using sodium sulphate solution as per IS 2386 (Part V) –1963. The aggregate samples have a solidity of 0.6%, compared to the maximum of 12% specified in the BIS standard.

Chemical Analysis

Representative samples of 2 kg each were drawn from each of the three overburden rock samples for chemical analysis by coning and quartering. Each representative sample was ground to a fine powder passing on 150 microns and used for the analysis of major and minor constituents in the crushed aggregates. The results given in table 4, indicate that three of the samples, viz., OB1, OB2, and OB3 were dolomitic limestone. The overburden rock sample OB3 had SiO_2, CaO, and MgO content of 43.20, 28.5, and 4.93 percent respectively, indicating siliceous limestone. The acid-soluble chloride and SO_3 are in trace amounts.

Table 4. Chemical Composition of crushed nominal aggregates (Wt%).

Sample	LOI	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O
OB1	34.6	32.44	19	3.23	1.59	7.73	0.45	0.25	0.31
OB2	37.8	33.9	13.07	2.41	1.29	10.62	0.52	0.36	0.14
OB3	15.6	28.5	43.2	4.44	3.13	4.93	0.3	0.11	0.23

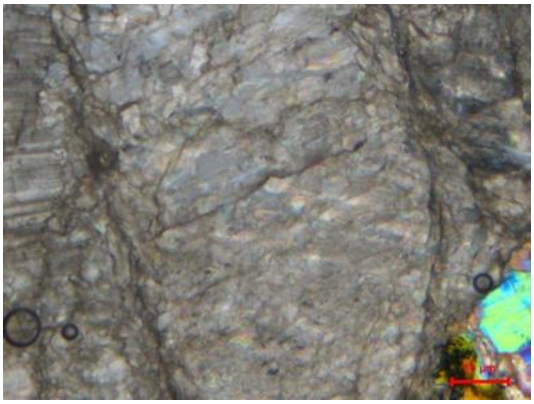

Fig. 7. Dolomitic Limestone: Coarse Dolomite.

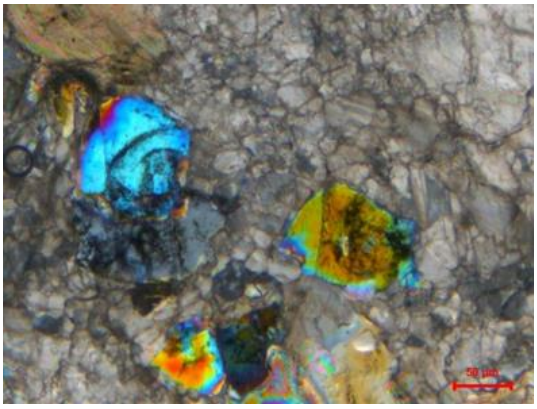

Fig. 8. Siliceous Limestone: Coarse Quartz.

Petrography

Texture and microstructural analysis of reject grade limestone samples were conducted by a petrological microscope (Leica DM 2500) using the thin section method. Texturally, the limestone is hard, compact, and coarsely crystalline. The mineralogy of overburden includes Dolomite ($MgCO_3$), Calcite ($CaCO_3$), Quartz (SiO_2), Biotite $K(Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$, Corderite (Mg, Fe)$_2$,$Al_4Si_5O_8$, Talc ($Mg_3Si_4O_{10}(OH)_2$, and Albite ($NaAlSi_3O_8$). From mineralogical analysis, it indicates that the rock types are dolomitic. All the images have been captured at 100X.

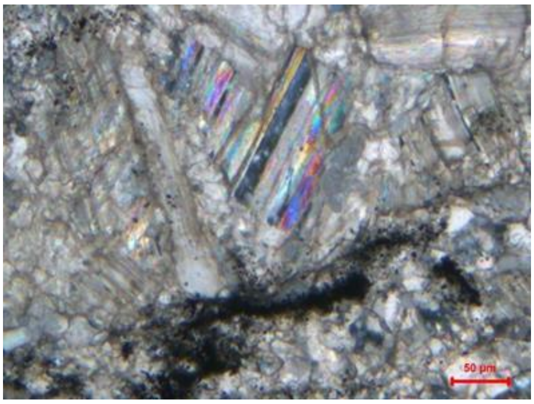

Fig. 9. Inclusions of orthoclase feldspar.

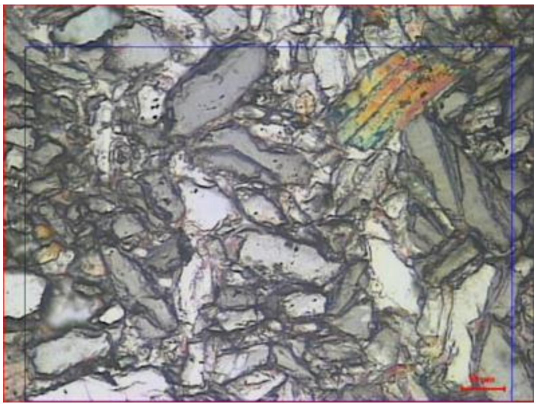

Fig. 10. Presence of Biotite in OB.

Concrete Mix Design

M25 grade concrete has been prepared as per IS 10262 -2019 with and without aggregate produced from dolomitic limestone. Mix A contains a control sample (without dolomitic aggregate) and Mix B contains 50 % replacement with 20 mm of dolomitic aggregate. The workability and strength parameters are given in Table 5.

Table 5. Concrete properties: M25 Concrete Mix Design.

Sl. No.	**Parameters**		
1	Grade of concrete	Mix A	Mix B
2	OPC 43 G (Kg/m^3)	220	220
3	Fly Ash (Kg/m^3)	118	118
4	M. Sand (Kg/m^3)	978	946
5	10 mm Aggregate(Kg/m^3)	509	492
6	20 mm Aggregate (Kg/m^3)	509	
7	20 mm Aggregate- Reject Grade Limestone (Kg/m^3)		492
8	Free Water (Kg/m^3)	155	155
9	W/C ratio	0.46	0.46

In Mix B, the slump value of 70mm at 1.5 hrs indicates the lower side is not recommended for pumpable concrete.

Table 6. Mechanical properties of Concrete.

		Mix A	Mix B
1	Density of concrete (Kg/m^3)	2491	2424
2	Workability at 1 hour in mm	Collapse	150
3	Workability at 1.5 hour in mm	200	70
4	Workability at 2.5 hours in mm	120	---
5	CCS @ 7days N/mm^2	20.55	16.18
6	CCS @ 28 days N/mm^2	30.04	25.79

Results and Discussion

All three crushed aggregate samples of 10 and 20 mm nominal size were prepared from hard, compact, and dense overburden stones and met the general quality requirement of aggregates specified in IS 383-2106(3) (Indian Standard–Specifications for Coarse and Fine Aggregates for Concrete). The chemical and mineralogical evaluation of overburden rocks indicated that these samples were of dolomitic limestone and siliceous limestone. Further, the specific gravity, bulk density, and water absorption of all the samples were in the normal range for natural stone aggregates, and the values lied in a close range, indicating consistency in the quality of aggregates prepared from overburden stone. Based on the test results on various properties as summarized above, all three overburden stones are considered suitable for the production of coarse aggregate for use in cement concrete.

All three aggregate samples (20mm) had crushing and impact values less than 30 percent thus meeting the requirements specified in IS 383-2016(3) for these properties for aggregates for use in concrete for wearing surfaces as well as for aggregates to be used in other concrete. The abrasion value of 20mm aggregate is less than 50 percent, which meets the requirements of IS 383- 2016(3) (other than the wearing surface). The content of total deleterious materials in all the crushed aggregate samples was less than 1 percent and met the requirement of a maximum of 5 percent total deleterious materials in coarse aggregate. All the crushed aggregate samples also met the requirements of maximum content of material finer than 75 microns, coal and lignite content, and clay lump content. 100 % replacement of 20 mm aggregate in M25 grade concrete shows marginally lower 28 days strength compared with normal aggregate.

Conclusions

Based on the present study, the following conclusions can be made:

1. During testing, the general quality of overburden reject grade limestone indicated that it was hard, compact, and dense.
2. Petrography of overburden rock samples indicated dolomitic and siliceous limestone.
3. The 20 mm nominal size crushed aggregates prepared from the overburden stone samples conformed to the requirements of IS 383-2106.
4. The crushed aggregates showed no potential for alkali-aggregate reactivity as per the chemical test method.
5. The crushed aggregate samples prepared from the overburden stone passed the sodium sulphate accelerated soundness test with a comfortable margin.
6. The test data indicated uniformity in the quality of crushed aggregates.
7. Based on the above chemical, mechanical, and mineralogical composition, the reject grade limestone can be considered suitable for the production of coarse aggregates for use in concrete.

References

IS 383 (2016) Coarse and Fine Aggregate for Concrete Specification.
IS 2386 (1963) (P 1 – P VII) – Methods of test for aggregates for concrete.
IS 10262 (2019) Concrete Mix Proportioning – Guidelines.

Note: A new method has been formulated by research scientists, Dr. A. Sadangi and Dr. P. Desai for utilization of the mining waste to aggregate. So, they have not followed any reference. However, they have followed different IS standards.

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