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Aggregate suitability studies of Middle Jurassic Samana Suk Formation exposed at Sheikh Budin Hill, Marwat Range, Pakistan

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Key words: Aggregate, CPEC, Trans Indus Ranges, Samana Suk Formation, Sheikh Budin Hill.

Abstract

An expected increase in demand of aggregates due to the upcoming and ongoing projects of western route of CPEC, there is a need of establishing new sources of aggregate in Trans Indus Ranges of Pakistan. In this context, limestone of Middle Jurassic Samana Suk Formation exposed at Sheikh Budin Hill, Marwat Range was investigated and sampled to depict its suitability as aggregate for the construction of roads with help of geological and engineering testing. The studied samples exhibit the tolerable values of all standard engineering parameters including Loss Angeles Abrasion (21.8%), Aggregate Impact (15.68%), Soundness (2.35%), Specific Gravity (2.57), water absorption (0.67%), Aggregate Crushing Value (12.99%), stripping of bitumen (<5%), coating of bitumen (>95%), Flakiness index (9.36%) and Elongation index (10.77%) proposed by the different national and international agencies like AASHTO, ASTM, BS and NHA. Petrographic analysis revealed that there is trivial possibility of Alkali Aggregate Reaction like ASR and ACR. The results of geological and engineering parameters recommend limestone of Samana Suk Formation as suitable aggregate for the base course, sub base coarse, asphalt and cement concrete.

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Introduction

Aggregates generally represent natural or crushed rock material used for the construction projects related to concrete structures, roads, asphalt bases and pavements etc. They are generally comprised of broken fragments of rocks formed either by weathering or by blasting of rocks. These are generally categorized on basis of their physical, geological and mechanical properties like grain size, shape, lithology, texture, strength, abrasion and soundness etc. Natural aggregates mainly include the gravel, sand and muddy sediments deposited by various natural processes like water, wind and glaciers. Among the natural sources of crushed aggregates, limestone is the easily available and frequently used rock type for this purpose.

In Pakistan, limestones are most commonly used as major source of natural aggregate for construction industry. Limestone deposits are the major constituent of different rock units exposed in the Himalayan ranges of northern and southern Pakistan including Samana Suk Formation, Margalla Hill Limestone, Kohat Formation, Wargal Limestone, Kawagarh Formation, Lockart Formation, Shekhai Formation, Lockart Limestone and Sakesar Limestone (Nizami, 2008; Rehman, 2009, 2017; Rehman *et al.*, 2016; Ahsan *et al.*, 2012; Shah, 2009). The initiation of mega project of China Pakistan Economic Corridor suddenly increased the demand of aggregate in Pakistan for construction of road and civil structures. The abrupt increase in the aggregate demand requires the demarcation of new quarries to meet this demand. Various good quality limestones are exposed along the whole alignment of western route of CPEC at different localities. In Hazara and Mansehra, Margallah Hill limestone, Samana Suk limestone, Kawagarh limestone and Lockhart limestone are available in bulk amounts which can be used as potential aggregates (Rehman *et al.*, 2016; Shah, 2009). In contrary to this, Wargal limestone, Samana Suk limestone and Sakesar limestone are excellently cropped out along the central sections of CPEC passing through the Salt Range and Trans Indus ranges which may act suitable sources for good quality aggregates.

Middle Jurassic Samana Suk Formation is well exposed and developed in the north western Himalayas of Pakistan including Salt Range, Trans Indus ranges, Samana Range, Kohat area, Kalachitta Range and Hazara area (Shah, 2009; Fatmi, 1977; Latif, 1970). Samana Suk Formation is mainly comprised of limestone with minor dolomite and marl in Trans Indus Ranges including Surghar Range and Marwat Range (Shah, 2009; Nizami, 2008; Nizami and Sheikh, 2009). Sheikh Budin Hill, the project area is situated in the southwestern part of Marwat Range in District Laki Marwat near Laki Cement Factory at distance of almost 11km (Fig. 1).

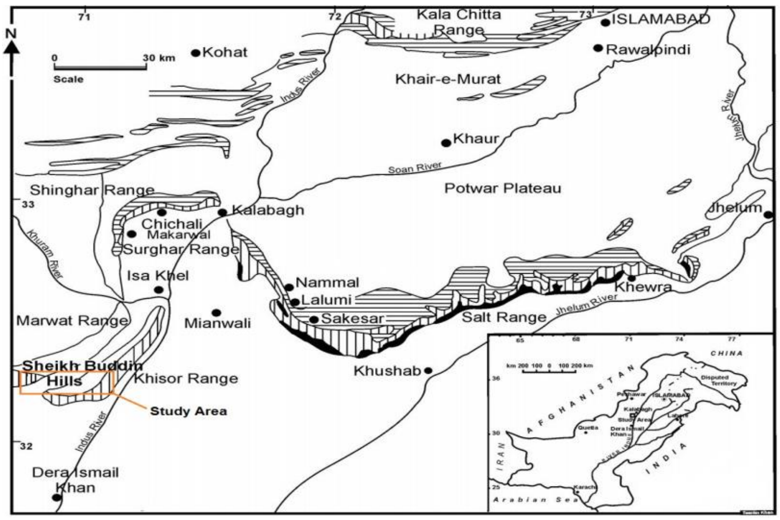


Fig. 1. Tectonic sketch map of Salt Range and Trans Indus ranges showing the location of study area Shiekh Buddin Hill, Marwat Range Pakistan (Modified after Gee, 1989).

The present paper deals with the engineering geological properties of Samana Suk Formation exposed at Sheikh Budin Hill to determine its suitability and utilization as road aggregate.

Materials and methods

Regional Geology

Trans Indus Ranges are the western extension of Salt Range across the Indus River and are represented by the small dissected mountains at the southern periphery of Sub Himalayas (Fig.1; Gee, 1989). These ranges mark the southernmost deformational front of Himalayan Orogeny with the undeformed sediments of Punjab platform (Hemphil and Kidwai, 1973).

Sheikh Budin Hill, the southernmost terminal of NS trending Marwat Range is characterized by the doubly plunging fold cut by three thrusts Sheikh Budin Thrust, Pezu Fault and Paniala Fault (Kazmi and Rana, 1982; Blisniuk, 1996). Sheikh Budin Hill crops out the sedimentary sequence ranging in age from Late Permian to Pliocene-Pliestocene with three main unconformities (Table 1; Fatmi *et al.*, 1999; Amjad 2010). The basal Late Permian strata is mainly composed of siliciclastic-carbonate package of Zaluch Group which is overlain by the rocks of Triassic Musa Khel Group (Fatmi *et al.*, 1999).

The Triassic rocks are followed by the siliciclastic-carbonate package of Jurassic to Cretaceous Surghar Group comprising of Datta Formation, Samana Suk Formation, Shinawari Formation, Chichali Formation and Lumshiwal Formation which are unconformably overlained by the Paleogene and Pliocene-Pliestocene rocks of Makarwal, Chharat and Siwalik groups (Fatmi *et al.*, 1999; Shah, 2009).

Table 1. Stratigraphic succession of Sheikh Budin Hill section, Marwat Range, Trans Indus Ranges, Pakistan (Modified after, Hemphil and Kidwai, 1973).

ERA	AGE	GROUP	FORMATION	Lithology
Cenozoic	Pliocene-Pleistocene	Siwalik Group	Dhok Pathan Formation	Sandstone & Clay
			Nagri Formation	Sandstone, Clay & Conglomerate
Unconformity				
Mesozoic	Cretaceous	Surghar Group	Lumshiwal Formation	Sandstone, Glauconitic Shale
			Chichali Formation	Glauconitic Shale & Sandstone
	Unconformity			
	Jurassic	Broach Group	Samana Suk Formation	Limestone, Marl & Calcareous Shale
			Shinawari Formation	Limestone, Marl, Shale and Quartzose Sandstone
			Datta Formation	Sandstone, Shale

Site Selection and Sampling

After thorough geological investigations from published geological literature, Sheikh Budin Hill was selected for the sampling of Middle Jurassic Samana Suk Formation. All outcrop characteristic including lithology, grain size, color, bedding pattern, thickness, lateral extension, fauna, contacts etc. were recorded to determine the geological suitability, workability and economic potential. On the basis of lithology, the outcrop was divided into different zones and suitable no samples were collected from each zone. Total ten samples were selected from different zones of the formation. Samples were transported to the laboratory for crushing and engineering testing.

Laboratory Testing

Selected samples were thin sectioned for petrographic analysis to determine the mineralogy, fabric and deleterious contents of Samana Suk Formation (ASTM C-295-1990). Crushed samples were used to determine the engineering properties by conducting various standard engineering tests proposed by different international agencies including American Association of State Highway and Transportation Officials (AASHTO), American Society for Testing and Materials (ASTM), British Standards (BS). A series of standard tests approved for the road aggregates including Los Angles abrasion (AASHTO T-96), soundness (AASHTO 104), specific gravity (AASHTO T-84D11-2009), water absorption (AASHTO T-84D11-2009), unit weight (AASHTO T-19), crushing value (BS 812 Part 110.1990), flakiness and elongation indexes (BS 812 Sec 105.1-1985 & 105.2-1990a), aggregate impact value (BS 812 Part 3:1975) and bitumen coating (AASHTO T-82) were conducted on crushed samples. The values of aforementioned tests were compared with the allowable ranges of international and national agencies including ASTM, AASHTO, BS and National Highway Authority (NHA) to determine the suitability of studied samples.

Results and discussions

Outcrop Geology

Samana Suk Formation is well developed and well exposed in Tans Indus ranges however in Marwat Range it is only exposed at the southern extremity range named as Sheikh Budin Hill (Shah, 1977, 2009). At Sheikh Budin Hill, Samana Suk Formation is mainly composed of grey to yellowish grey, medium to thick bedded limestone with minor dolomitic limestone, dolomite and shale and marl intercalations (Nizami, 2008; Shah, 2009; Nizami and Sheikh, 2009). Limestone is generally fine to coarse grained, hard and massive. It is oolitic at places. Some micritic beds also occur at places. Broken pieces of shells occur at various levels of formation. Minor constituents of Samana Suk Formation including dolomitic limestone, dolomite, shale and marl generally inter bedded within limestone and their total content does not exceed than the 10% of the total rock unit. The formation was divided into six zones on the basis of variation in lithology including SSZ-1 to SSZ-6, from base to top respectively. The five zones including SSZ-1, SSZ-2, SSZ-3, SSZ-5 and SSZ-6 are dominantly composed of limestone with minor dolomitic limestone while the one zone (SSZ-4) is composed of dolomite with minor shale/marls.

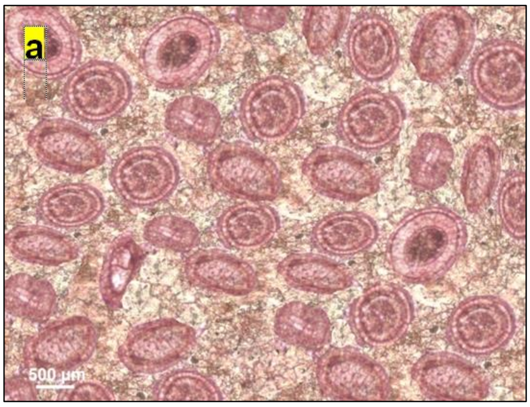
Two samples from each zone were collected for engineering testing except the SSZ-4. The maximum thickness of formation is recorded up to 88m (Nizami, 2008). The formation generally formed the cliff faces and steep slopes.

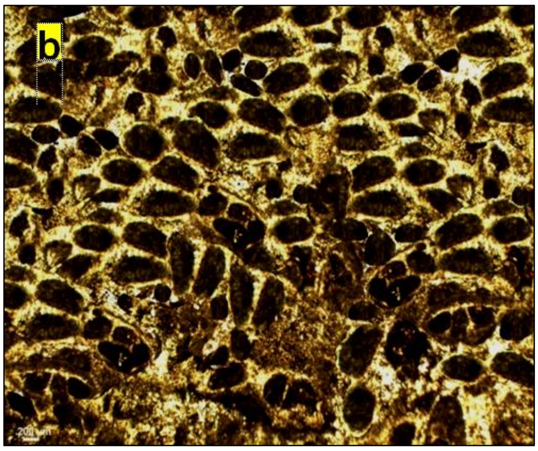
Petrography

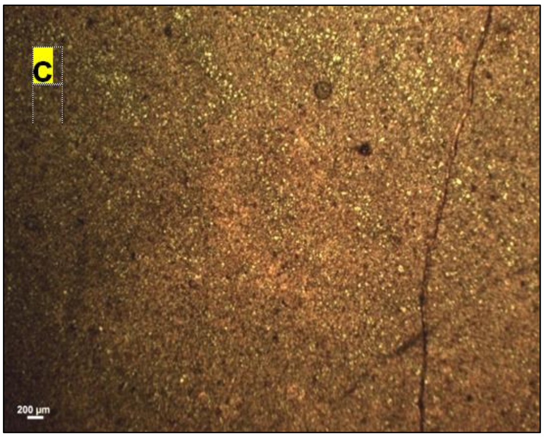
The petrographic analyses are generally conducted to determine the mineralogy, grain types, grain size and fabric of rocks. Unlike the rocks, petrographic analyses are significantly used in aggregates characterization to determine the reactive constituents (ASTM C-125-1990). The reactive constituents act as deleterious materials which generally affect the bonding and strength of aggregates due to various reactions including Alkali Silica Reaction (ASR) and Alkali Carbonate Reaction (ACR) when they interact with water (Neville, 2012; Khan *et al.*, 2008; Ahsan *et al.*, 2012).

The petrography of selected samples from all zones of Samana Suk Formation shows that it is mainly composed of calcite with minor content of dolomite, quartz and clays. Calcite generally constitutes the matrix and commonly appears as sparite and micrite (Fig. 2 a,b,c,d). The skeletal and non skeletal grains generally constitute the major fraction of studied samples which are distributed over the sparry matrix. Skeletal grains mainly include the broken fragments of various shells and miliolids and non skeletal grains are commonly comprised of oolites and peloids. The studied samples are classified as Ooidal grainstone (Fig. 2a), Peloidal packstone and grainstone (Fig. 2b), Bioclastic mudstone and wackestone (Fig. 2c) and Bioclastic packstone and grainstone (Fig. 2d) on classification of Dunham (1962). The dolomite generally occurs as medium grained individual crystals of dolomite which are generally appear over the sparry matrix and broken shells. The dolomite content generally varies from 5% to 7% in dolomitic limestones and its content is very low (<1%) in limestone. Quartz is generally detrital in origin and occurs as medium to coarse grained. The clay content is generally very low but it may exceed in some samples where the limestone beds are in contact with shale/marl horizons.

The skeletal and nonskeletal grain types and depositional fabric suggest that the Samana Suk Formation was deposited under restricted shallow marine conditions. Nizami (2008) and Nizami and Shiekh (2009) confined the deposition of Samana Suk Formation exposed at Sheikh Budin Hill in restricted lagoonal setting. The petrographic analysis of selected limestone samples of Samana Suk Formation shows the very minute deleterious content (dolomite and clay) in the studied samples which suggest insignificant threat of ACR and ASR and recommend the Samana Suk Formation exposed at Sheikh Budin Hill as suitable source.







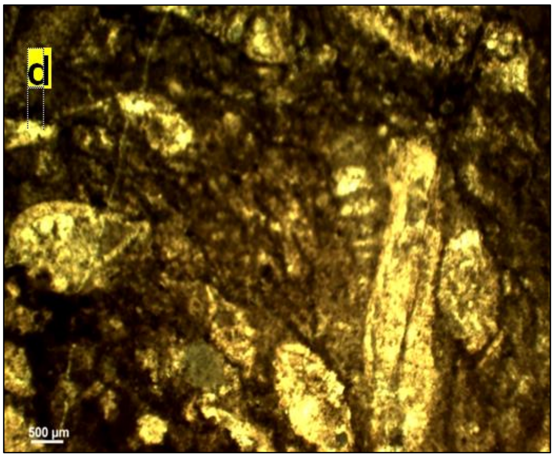


Fig. 2. a) XPL, 10X Ooidal grainstone. b) PPL, 4X Peloidal grainstone. C) PPL, 4X Sparry matrix in the mudstone. d) PPL, 4X Bioclastic mudstone.

Los Angles Abrasion

Los Angles Abrasion is the measure of abrasion and grinding ability of an aggregate (AASHTO T-96). It basically provides the wear and tear impact of aggregates when they subjected to anomalous loads during their service. The elevated rates of wear and tear in aggregates generally affect the life of civil structures (Khan *et al.*, 2008). So a good aggregate must have a significant resistance against these forces. Loss Angeles Value in studied samples of Samana Suk limestone varies from 21.1% to 22.9% against the maximum tolerable value of 35%, 40% and 50% for concrete, base course and sub base course, respectively (Table 2).

Soundness

Soundness defines the resistance of an aggregate offered against the weathering and erosion under natural conditions (AASHTO 104). In field, aggregates are exposed to various weathering conditions like freezing and thawing, wetting, drying and thermal changes which generally ruin the structure of aggregate and decrease the life of civil structures (Kazi and Al-Mansur, 1980; Gondal *et al.*, 2009; Ahsan *et al.*, 2012). For good quality and efficient aggregate it should be enough resistant against the weathering and erosion (Gondal *et al.*, 2009). The soundness value ranges from 2.23% to 2.45% in the studied samples of Samana Suk Limestone against the maximum value of 4% (Table 2).

Table 2. Aggregate test results of Summana Suk Formation.

Sample No.	Los Angles Abrasion %	Soundness Test %	Specific Gravity	Water Absorption %	Unit Weight g/cc	Crushing Value %	Flakiness Index %	Elongation Index %	Aggregate Impact Value	Bitumen Coating
1	21.1	2.23	2.51	0.65	1.64	13.1	8.9	10.7	15.5	> 95%
2	21.4	2.27	2.56	0.61	1.68	12.9	9.5	10.4	15.9	> 95%
3	22.5	2.4	2.61	0.63	1.7	12.8	9.3	10.3	15.4	> 95%
4	21.9	2.43	2.52	0.69	1.65	13.2	8.9	11.1	15.1	> 95%
5	21.2	2.38	2.53	0.71	1.65	12.7	8.7	10.5	16.1	> 95%
6	21.6	2.31	2.57	0.65	1.67	12.9	9.7	11.2	15.6	> 95%
7	22.4	2.24	2.62	0.68	1.69	13.3	10.1	10.9	15.8	> 95%
8	22.1	2.44	2.63	0.73	1.7	13.1	10.3	11.1	15.1	> 95%
9	21.7	2.45	2.55	0.72	1.64	12.7	9.3	10.3	16.2	> 95%
10	22.9	2.35	2.59	0.69	1.65	13.2	8.9	11.2	16.1	> 95%
Average	21.8	2.35	2.57	0.67	1.66	12.99	9.36	10.77	15.68	> 95%

Specific Gravity and Water Absorption

Specific gravity is the ratio of a mass of material compared to mass of equal volume of water. Specific gravity is used as indicator of the quality of an aggregate as higher the specific gravity better is the quality of aggregate (AASHTO T-84D11-2009). Water absorption is the measure of pore ratio in an aggregate. The rocks with higher pore ratio are characterized by the higher value of water absorption (Lees and Kennedy, 1975). Aggregates with higher absorption values are not considered good aggregates because water caused various reactions within pores which can affect the strength of aggregates (Neville, 2012). The Specific Gravity (oven dry) of studied samples of Samana Suk limestone ranges from 2.51 to 2.63 whereas the water absorption varies from 0.61% to 0.73% (Table 2) which corresponds to range of best quality aggregates prescribed by ASTM (2004).

Unit Weight

Unit Weight of an aggregate is very useful parameter to evaluate the weight to volume ratio and void ratio (AASHTO T-19). These ratios are used as important factors in mix designs and estimation of reserve stocks (Corney and Corney, 1997; Neville, 2012). The aggregates with higher values of unit weight are generally considered as good and efficient aggregates due to the less void ratio (Masad *et al.*, 2006). Less void ratio generally decreased the water absorption in aggregates which avoids the reactions and damages within the aggregate particles (Corney and Corney, 1997). The unit weight values in the studied samples of Samana Suk Formation vary from 1.64 to 1.70 (Table 2).

Crushing Value

Crushing value is the measure of resistance in aggregate particles offered to rupture (BS 812 Part 110.1990). Inversely, it is used to determine the strength of aggregate as they subjected to static and moving stresses like overburden in civil structures and load of traffic rolling on the road (Khan *et al.*, 2008; Ahsan *et al.*, 2012). Aggregates with high crushing values are considered capable to bear the high compressive stresses applied on them (West, 1996). The aggregate crushing values of studied samples of Samana Suk Formation exposed at Sheikh Budin Hills vary from 12.8% to 13.3% (Table 2) which are comparable with good quality aggregates as prescribed by ASTM (2004) and AASHTO (2009).

Flakiness and Elongation Indexes

Flakiness and elongation indexes define the shape control of aggregate particles in an aggregate (BS 812 Sec 105.1-1985 & 105.2-1990a). Particle shape is also an important parameter in aggregate characterization as shape may cause breakage or deformation in particles when aggregates are subjected to heavy traffic load. Breakage and deformation of particles generally affect the workability of roads (Khan *et al.*, 2008; Ahsan *et al.*, 2012). Higher values of flakiness and elongation indexes results in lower workability. The values of elongation index and flaky index in studied limestone samples of Samana Suk Formation range from 10.3% to 11.2% and 8.7% to 10.3%, respectively (Table 2). These values are significantly lower than the maximum limit of AASHTO (2009) and ASTM (2004).

Aggregate Impact Value

Aggregate Impact value is the measure of toughness or the resistance upon a sudden shock which is not proportional to the resistance of a slowly applied compressive stress (Neville, 2012). Toughness of coarse aggregate is evaluated from aggregate impact value test (BS 812 Part 3:1975). This test basically reveals the opposition of a material against the repeated impacts of stresses when subjected to heavy traffic load (Ahsan *et al.*, 2012). The impact value in coarse aggregates should be less than 35% for use in roads. The aggregates with impact value ranging between 10% and 20% are generally considered as very good aggregates (BS 812 Part 3:1975). Aggregate impact value of Samana Suk Formation exposed at Sheikh Budin Hills varies between 15.1% and 16.2% which infer it as good quality source (Table 2).

Coating and Striping of Bitumen

This test is used to evaluate the retention of bitumen film on an aggregate surface in the presence of water (AASHTO T-182; Corney and Corney, 1997). Coating and striping of bitumen is significant parameter which defines the cohesion capacity of aggregate particles with bitumen in topmost asphalt layer under the water action (AASHTO T-182). Aggregate used in asphalt layer must have good cohesion with bitumen and it must retain its cohesion under the action of water and moisture (Ahsan *et al.*, 2012). Stripping Value of all the samples of Samana Suk Formation was below 5% using 80/100 grade bitumen and coating value was recorded above the 95% (Table 2). The values of coating and striping of bitumen are comparable with international standards and designate Samana Suk Formation as excellent source.

Discussion

The Middle Jurassic Samana Suk Formation is well developed and well exposed in the parts of Salt Range and Trans Indus ranges including Surghar, Khisor and Marwat ranges (Nizami, 2008; Shah, 2009; Nizami and Sheikh, 2009). In present study, field investigations show that Samana Suk Formation is excellently cropped out at Sheikh Budin Hill area with a total thickness of about 88m and is mainly composed of limestone with minor dolomitic limestone, dolomite and shale/marl.

Limestone is generally grey to yellowish grey with medium to thick bedding. Limestone constitutes the more than 95% of the total thickness of formation. Limestone samples of Samana Suk Formation derived from the study area were subjected to different standard geological and engineering tests devised by the different international societies and organizations to determine the values of engineering parameters.

The results of different engineering parameters including Loss Angeles Abrasion (21.8%), Aggregate Impact Value (15.68), Soundness (2.35%), Specific Gravity (2.57), water absorption (0.67%), Aggregate Crushing value (12.99%), stripping of bitumen (<5%), Bitumen Coating (>95%) Flakiness index (9.36%) and Elongation index (10.77%) show that the studied samples of Samana Suk Formation excellently qualify the permissible ranges these engineering parameters as allowed by different Agencies like AASHTO (2009), ASTM (2004), BS (1990) and NHA (1998) for base course, sub base course, asphalt and cement concretes. The values of these parameters are excellently comparable with other good quality aggregates sources exposed in Salt Range, Kirana complex and adjacent areas (Khan *et al.*, 2008; Ahsan *et al.*, 2012). The thin section studies of selected limestone samples show that limestone is mainly comprised of different carbonate skeletal and nonskeletal grains including bioclasts, oolites and peloids which are distributed over sparry and micritic groundmass. Dolomite and detrital quartz also occur in minor amounts. Petrographic analysis of limestone samples clearly negated the of presence of any deleterious material above safe limits which designate the Limestone of Samana Suk Formation as non-reactive aggregate and can be used in roads and concrete along with high alkali cements or ordinary Portland cement without the threat of Alkali Aggregate Reactions.

The topography of Sheikh Budin Hill suggests that the outcrops of Samana Suk Formation are excellently workable at no of localities as aggregate quarries. Steep ridges and cliffs can easily be mined following blasting methods whereas the gentle slope areas can be worked out by open pit mining.

Rock crushing units can be established on piedmont planes in front of Hills. Furthermore, the study area is closed to national highway N-55, the main road connecting Bannu and D.I. Khan which can be used in transportation of crushed and un-crushed rocks.

Conclusions

The present study concludes the followings:

1. Samana Suk Formation is well developed and well exposed in the Sheikh Budin Hill area with a maximum thickness of about 88m.
2. The petrographic analysis shows the presence of very minute amounts of deleterious contents in limestone of Samana Suk Formation which geologically designate it as suitable aggregate source.
3. The values of all engineering parameters are comparable with standard values of AASHTOO, ASTM, BS and NHA which infer the limestone of Samana Suk Formation as excellent aggregate source.

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