Journal of Himalayan Earth Sciences Volume 54, No. 1, 2021 pp. 1-10

Engineering and petrographic properties of meta dolerite aggregates of Kirana Hills of Sargodha, Punjab, Pakistan

Muhammad Nawaz Chaudhry[1]*, Muzaffar Majid[2], and Uzma Ashraf[1]
[1]Department of Environmental Sciences and Policy, Lahore School of Economics, Lahore
[2]College of Earth and Environmental Sciences, University of the Punjab, Lahore
**Corresponding author's email: muhammadnawazchaudhry@yahoo.com*
Submitted date: 21/02/2017 Accepted date: 24/02/2021 Published online: 31/03/2021

Abstract

Kirana, Rabwa and Chiniot areas of the Punjab province, Pakistan has a number of isolated hills jutting out of a flat alluvial plain. These rocks are Upper Proterozoic in age. The exposed volcano-sedimentary sequence is slightly metamorphosed (lower greenschist facies). The dolerites have also undergone auto metasomatic changes. The Kirana Hills are the main resource of aggregate in southern and middle Punjab. These aggregates are used in subbase, base course, in rail ballast, as riprap and for the cement and asphalt concrete. The main lithologies in Kirana Hills are dolerites and rhyolites, lithic greywackes, volcanogenic slates and quartz wackes. This paper deals only with the dolerites and their petrographic composition and engineering properties, as well as adhesion values. The variably auto metasomatized dolerites are now composed of variable amounts of plagioclase, chlorite, calcite and amphibole with quartz, magnetite, hydro mica, K-feldspar, epidote and sphene as subordinate to accessory minerals. Flakiness, Elongation, Specific Gravity, Water Absorption, Soundness, Los Angeles, Aggregate Crushing, Aggregate Impact and Adhesion Values are all within ASTM limits. Therefore, the dolerite aggregates of Kirana area have excellent Engineering Properties. They can also be used for subbase, base course and riprap material. However, quartzites, lithic greywackes, volcanogenic slates and rhyolites which can be used for these purposes are available in the area, therefore dolerites should not be used because they are the only good source of asphalt concrete and especially for the wearing course (since it gives a good road grip and resists polishing) in Punjab province with an area of 205344 km2. Dolerites should be reserved for cement and asphalt concrete. Petrographic studies show that dolerites do not have Alkali-Silica Reaction Potential and are hydrophobic and can be used for cement as well as asphalt concrete. This area has total estimated 3097.3 million tons of reserves of all types of aggregates. The aggregate resource map of this important area is being presented for publication for the first time.

Keywords: Dolerites, Engineering properties, Kirana hills, Petrography, Pakistan.

1. Introduction

Aggregate manufacturing is one of the leading industries in the world (Neville, 2000). Aggregates are defined as particles of rock, which when brought together in bound or unbound conditions, form part or whole of engineering or building structure (Neville, 2000). With the initiation of China Pakistan Economic Corridor (CPEC) (involving an investment of more than 65 billion dollars in infrastructure (Hussain, & Khan, 2017), there will be a great demand for innocuous and hydrophobic aggregates.

In order to meet the requirement of CPEC related infrastructure projects, hundreds of millions of cubic meters of aggregates will be required for the new highways, motorways, power projects, housing schemes and railways. Suitable engineering and petrographic properties are a prerequisite for use of these aggregates (Smith and Collis, 1993; Neville, 1981, 2000). This paper deals with the petrography and engineering properties of dolerites of Hachi Formation of Proterozoic age (Table 1).

The Hachi Volcanics contain dolerites (including all mafic suites which have been defined petrologically as the equivalent of tholeiitic basalts and basaltic andesites, felsic volcanic (mainly rhyolites and minor association of andesites and dacites) and volcanogenic slates that are interbedded with the volcanic (Table 1) (Chaudhry et al., 1999).

1.1. Geology of the area

In the Kirana Area, there are around 40 isolated hills surrounded by alluvium of the Punjab plain. The rocks of these hills are a part of an extensive volcano-sedimentary sequence known as Malani Basin (Kochhar, 1984, 1998, 1999, 2000; Bhushan, 1999) now redesigned as Kirana-Malani Basin (Chaudhry et a., 1999).

The geology and stratigraphy of the Kirana hills have been discussed by Shah (1973) and modified by Alam and Alam et al. (Alam, 1987; Alam et al., 1992). Chaudhry et al., 1999 further modified the stratigraphy of the area. The rocks of the area are upper Proterozoic in age and consist of bimodal cratonic rift assemblage volcanics. These are composed predominantly of dolerites and rhyolites. Subordinate lithologies consist of volcanogenic slates, andesites and dacites. Kirana Hills area is playing a vital role in the generation of revenue (directly or indirectly) for the Punjab province. This area has total estimated reserves of about 3097.3 million tons" (Khan, 2000). The reserves of aggregates comprising of dolerites are important for cement and asphaltic concrete. They are unconformably overlain by Tuguwali Formation consisting of pelites and psammites which are in turn overlain by Asian Wala Quartzite comprising of lithic greywacke and quartz wacke, Hadda Formation comprising of calcareous quartzites overlain in turn by a conglomerate with slate intercalations.

1.2. Stratigraphy

The oldest unit in the area is the Hachi Volcanics which contain dolerites. This unit is overlain by a conglomerate which is in turn overlain by Machh Super Group of metasediments. The stratigraphy of the area is summarized in Table 1 (Chaudhry et al., 1999).

1.3. Dolerites

The Kirana Hills area aggregate deposits are comprised of igneous and metasedimentary rock suites (Shah, 1973, 1977; Alam, 1987; Dolan et al., 1987; Khan and Chaudhry, 1991; Chaudhry et al., 1999). The igneous rocks are comprised of dolerite sills and dykes, rhyolites, andesites and pyroclasts (Khan and Chaudhry, 1991).

The geology of the area is shown in Fig. 1 (Khan, 2000). The dolerites occur as sills and dykes with variable thickness. They have undergone autometasomatism of variable degrees producing minerals like chlorite, calcite and epidote.

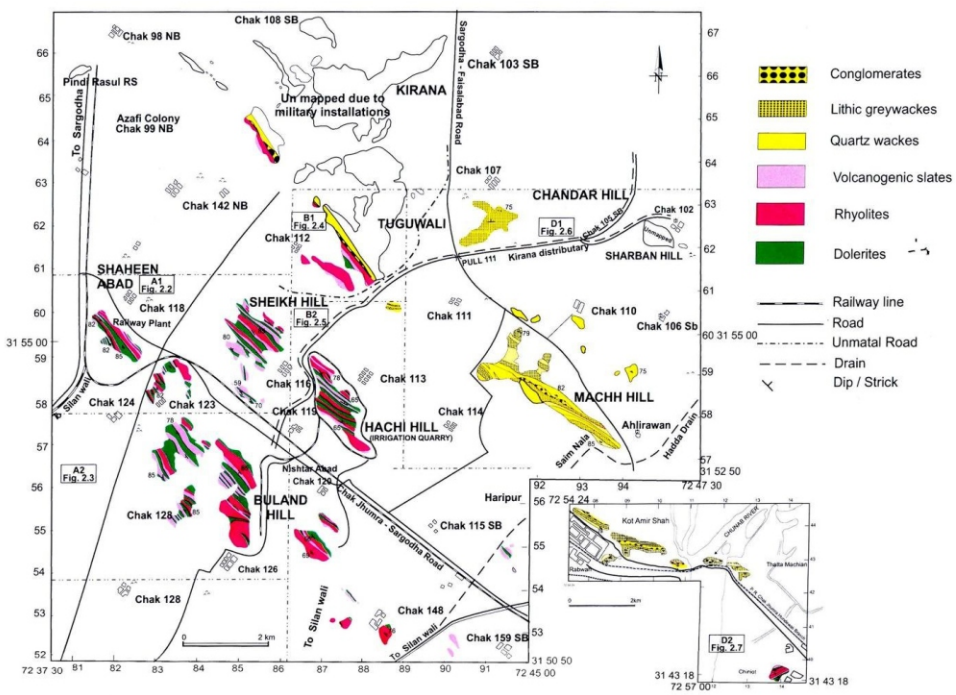

Fig. 1. Geological Resource Map of Kirana Hills Area (Khan, 2000).

Table 1. Stratigraphic Classification of Kirana Area (Chaudhry et al., 1999).

Group	Formation	Description
Machh Super Group	Sharaban Formation	Conglomerates with slate intercalations
	Hadda Formation	
	Asianwala Formation	Calcareous Quartzites
	Tuguwali Formation	Mainly quartzites with subordinate quartz wackes/arenaceous slates, gritty quartzites and slates, often showing cross-bedding and ripple marks.
	Chak 112 Conglomerate	Slates, fine-grained quartz wackes/arenaceous slates.
	Volcanogenic Slates	Polymict conglomerate with clasts of dolerite and acid volcanics.
	Volcanics	Often interbedded with rhyolite/rhyolitic tuff and dolerite.
Hachi Volcanics		Dolerites, andesites, dacites, dacitic tuff, rhyolites and rhyolitic tuff.

2. Materials and methods

The problem of sampling aggregate deposits from bedrock as well as from gravel and sand has been discussed in detail by a number of authors (Fookes et al., 1988; Khandal and Parker, 1998; Smith and Collis, 1993; Mielenz, 1994, Neville, 2000; Dhir et al., 1977). Random sampling of dolerites, sills and dykes was carried out in accordance with ASTM C 3665-99.

In the Kirana Hills area, the aggregates are either being produced by crushing individual rock types, such as dolerites separately in jaw crushers or a mixture of various rock types derived from Hachi Volcanics and Machh Super Group crushed in plants. In case of jaw crushers, the raw material is selected manually for crushing.

The petrographic analyses were carried out under petrographic polarizing microscope. The quantitative mineral composition was determined using point counter. The engineering properties were determined using ASTM standards which have been cited in the section "Results and Discussion".

3. Results and discussion

3.1. Petrography of dolerites of kirana hills

The rocks are fine to medium grained, hypidioblastic and sub-blastoporphyritic. Modal analyses of 15 representative samples are given in Table 2, and micro photographs of a medium and fine grained meta dolerite are given as Fig 2 and 3.

Plagioclase is andesine to labradorite. It occurs predominantly as subhedral crystals. It is variably altered to calcite and epidote. It varies from 20.4% to 30.5%.

Amphibole is accessory to essential mineral. It is mainly subidioblastic. It varies from 0.5% to 10.8%.

Chlorite is an essential mineral and varies from 20.7% to 52.5%. It is a secondary mineral and formed due to the alteration of pyribole.

Calcite occurs either as discrete grains or aggregates. It develops mainly due to the alteration of plagioclase. It amount varies from 4.5% to 19.2%.

Quartz is an accessory mineral and occurs mainly as anhedral crystals. It varies from 2.2% to 4.5%.

Magnetite is an accessory mineral. It is anhedral and varies from 5.1% to 6.9%.

Hydromica forms due to the alteration of feldspar. It varies from 2.0% to 2.5%. It is a reactive mineral but its amount is within safe limits.

K-feldspar is an accessory mineral. It is an orthoclase. It alters to sericite. It varies from 3.1% to 4.5%.

Epidote occurs as anhedral crystals and varies from 0.4% to 9.2%.

Sphene is ubiquitous accessory mineral and varies from 0.5% to 2.0%.

The quantity of quartz varies from 2.2% to 4.5%. The dolerites do not have Alkali-Silica Reaction (ASR) Potential and can be used as aggregate in cement concrete using high alkali cement. Since the quantity of hydrophilic mineral varies from 2.2% to 4.5%. It is within permissible limits and the rock can be used for bitumen concrete. The total deleterious constituent of the minerals is between 2.0% to 2.5%, therefore the dolerites are innocuous and have no Alkali-Silica Reaction (ASR) Potential.

Table 2. Petrographic Modal Analysis of Dolerites of Kirana Hills

Samples	Plagioclase	Chlorite	Calcite	Quartz	Magnetite	Hydromica	K-Feldspar	Epidote	Amphibole	Sphene
S1	28.4	20.7	18.6	4.3	6.4	2.1	3.6	5.4	8.6	1.9
S2	24.6	31.4	19.2	4.5	5.1	2.3	3.5	6	1.5	1.9
S3	26.2	29.0	12.7	2.2	6.6	2.3	3.4	7.3	9.5	0.8
S4	27.2	52.5	4.5	2.2	6.4	2.1	3.1	0.5	0.5	1
S5	25.4	47.0	11.8	2.6	6.2	2.2	3.3	0.4	0.5	0.6
S6	20.4	30.5	17.4	2.6	5.9	2.2	3.2	9.2	8.1	0.5
S7	27.7	42.6	6.9	4.4	6.8	2.2	3.4	1	4.5	0.5
S8	29.2	35.5	16.5	4.3	6.9	2	3.1	1	1	0.5
S9	26.4	45.4	10.5	3.5	6	2.1	3.2	1.2	1	0.7
S10	21.9	26.3	19.1	4.1	5.8	2.3	3.4	4.8	10.8	1.5
S11	29.2	39.6	15.2	2.3	5.4	2.2	3.2	0.4	2	0.5
S12	28.4	41.7	11.4	4.2	6.5	2.2	3.5	0.8	0.5	0.8
S13	28.4	30.7	18.6	4.3	6.4	2.1	3.6	2.4	1.6	1.9
S14	22.8	25.4	18.5	4	6	2.5	4.5	7.4	6.9	2
S15	30.5	35.5	14.0	3.5	5.5	2	4	2.5	1.5	1

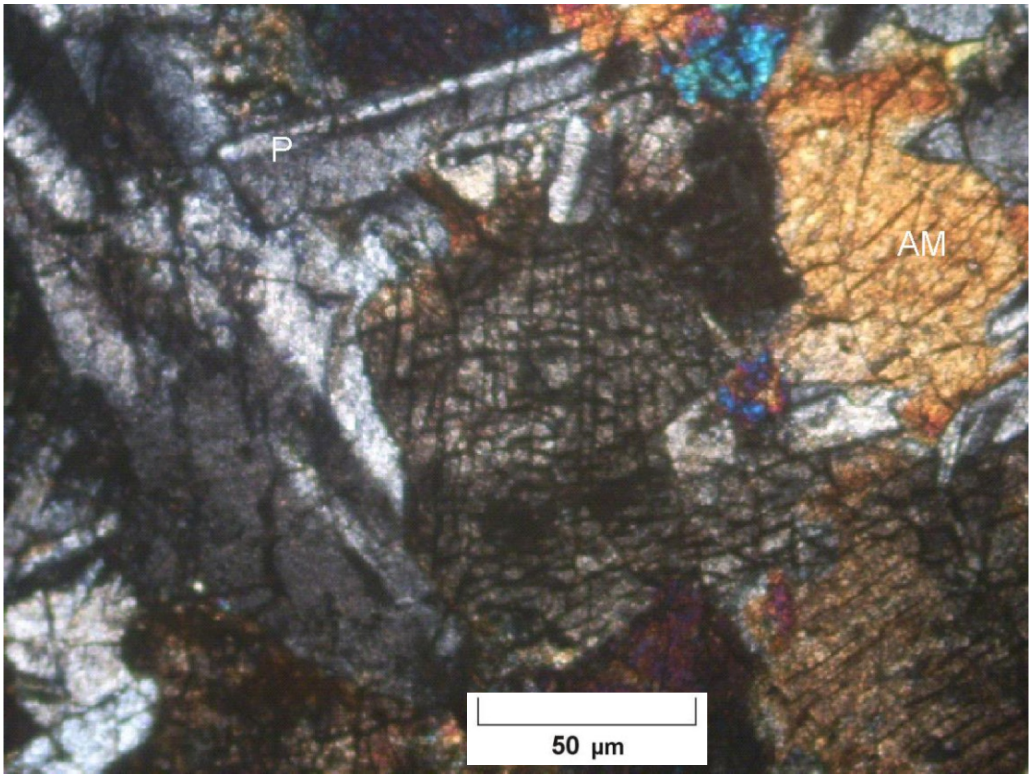

Fig. 2. Meta dolerite, Amphibole (AM) and Plagioclase (P) (Cross Nicol)

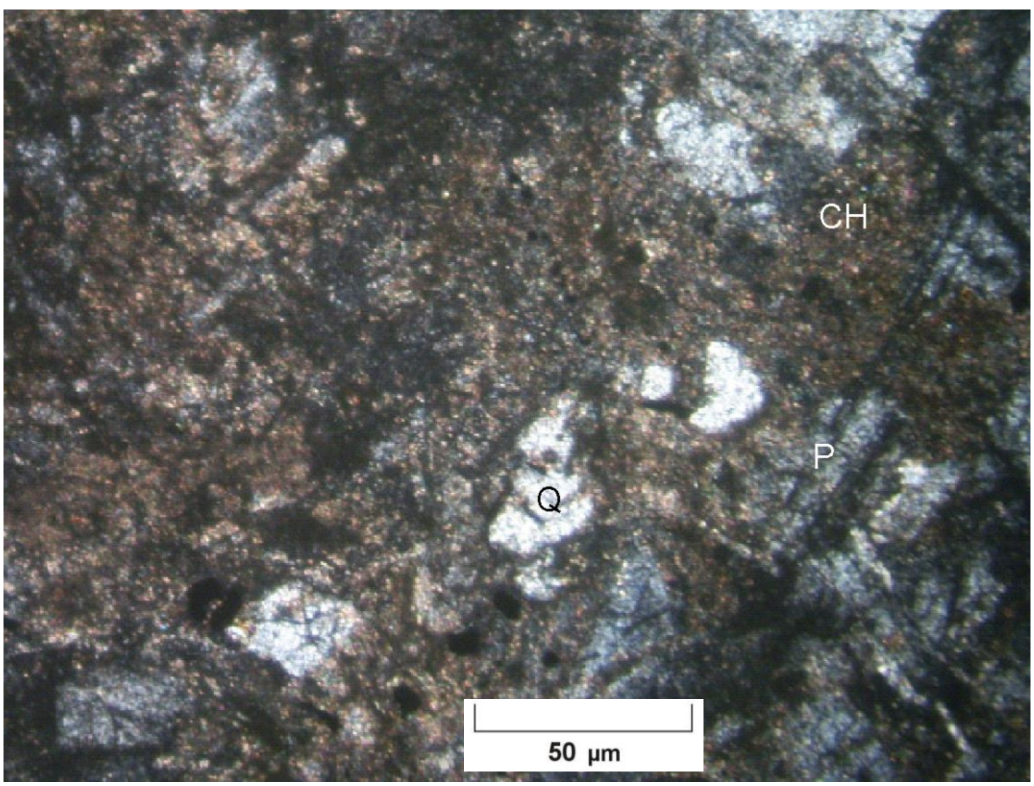

Fig. 3. Meta dolerite, Chlorite (CH), Quartz (Q) and Plagioclase (P) (Cross Nicol)

3.1. Engineering properties of dolerites of kirana hills

Quality assurance and in-service performance (BS 7570) of aggregates is based on their engineering characteristics, which are predominantly mechanical in nature and are carried out in accordance with national standards. However, in Pakistan, these tests are performed in accordance with American Society for Testing and Materials (ASTM) or British Standards (BS).

Materials with adequate strength and durability are effectively capable of resisting the loss of cohesion and strength. Such materials are capable of making good bonds with cement and withstand impacts (Neville, 2000).

3.2.1. Flakiness index and elongation index

Mineral shape, minerals interrelationship (texture) and structure (fabric) control flakiness and elongation. The flakiness and elongation indices were determined according to (ASTM C-4791). The values of flakiness Index and Elongation Index for dolerites range from 14% to 33%. (Table 3 and Fig 4). The aggregates being produced at present in low-tech jaw crushers tend to increase the values of flakiness and elongation. Gyratory methods used in two-stage crushing can reduce these values.

3.2.2. Specific gravity

The specific gravity was determined according to (ASTM C-128-93). The values of specific gravities for dolerites range from 2.6 to 3.0 (Table 3). Specific gravity of pure dolerite composed only of Plagioclase and Pyroxene is generally from 3.00 to 3.05. The reason for variation in specific gravity of dolerite of the Kirana area is the presence of various quantities of auto metasomatic minerals like calcite, hydromica and even chlorite.

3.2.3. Water absorption

It is a measure of porosity and indirectly a measure of the strength of the rock. The water absorption was determined according to (ASTM C-128-93). The values of water absorption for dolerites range from 0.2% to 1.2% (Table 3).

3.2.4. Soundness test

This test is a measure of resistance to loss of cohesion and strength due to the biophysical environment (weathering). The soundness was determined according to (ASTM C-88). The values of soundness for dolerites range from 3.2% to 5.8% (Table 3 and Fig 4).

3.2.5. Aggregate impact value and aggregate crushing value

These two tests were performed on the samples according to BS 812: part 112 and 110. The values of aggregate impact value and aggregate crushing value for dolerites range from 9.0% to 22.0% (Table 3 and Fig 4).

3.2.6. Los Angeles abrasion value

Aggregate Impact, Aggregate Crushing and Los Angeles Abrasion Values are the basic strength parameters to evaluate the strength and durability of the aggregate. The Los Angeles abrasion value was determined according to ASTM C-33-90. The values of Los Angeles abrasion for dolerites range from 9% to 17% (Table 4 and Fig. 4).

3.2.7. Aggregate adhesion value

The most important factors in the case of aggregates in bituminous bound and unbound construction material are the petrographic properties. The strip test (IS:6241-1971) has now been supplemented by petrographic test which evaluates the quantities of hydrophilic minerals. This procedure has shown excellent results and has now been adopted in Pakistan (Chaudhry and Khan, 1993). Mineralogy controls the bitumen aggregate bonding, depending upon the presence of the hydrophilic and hydrophobic minerals. (Lees and Salehi, 1967; Porubszky et al., 1969; Terrel and Shute, 1989; Jamieson et al., 1995; Robertson, 2000). Adhesion failure is a breakdown of bonding and physical separation between a particle and bituminous binder (Jamieson et al., 1995). Adhesion values of Kirana dolerites range between 96% to 98% (IS 6241-1971). Kirana dolerites contain a low percentage of quartz which is hydrophilic constituent. Kirana dolerites will therefore make a good bond with bitumen.

3.3. Pearson correlation

Pearson correlation matrix is given as Table 4. There is a weak correlation between the engineering parameters. The reasons for weak correlation are that there are a large number of dolerites dykes and sills with very different dimensions (from a few meters to hundreds of meters thick). They also differ in texture as well as internal structure (fractures and joint patterns). The intensity of auto metasomatism and mineral proportions also vary widely.

Therefore, the for civil structures each dyke or sill should be tested separately, and that engineering properties of one sill or dyke should not be considered applicable to other sills and dykes.

Table 3. Engineering Tests Performed on Dolerites of Kirana Aggregates

Samples	Flakiness %	Elongation %	Specific Gravity %	Water Absorptions %	Soundness %	Los Angeles %	Aggregate Crushing Value %	Adhesion Value %
S1	22	31	2.9	0.6	4.8	13	9	96
S2	24	29	2.8	1.2	4.9	13	8	96
S3	19	37	3.0	1.1	4.7	14	10	98
S4	21	24	2.6	0.9	4.5	15	11	98
S5	26	28	2.7	0.8	5.8	12	7	98
S6	18	33	2.9	0.6	3.6	14	12	98
S7	17	27	2.8	0.5	3.3	11	8	96
S8	19	26	2.9	0.7	3.4	11	12	96
S9	25	28	2.7	0.8	3.5	11	6	97
S10	24	30	2.9	1.2	4.3	14	11	96
S11	27	31	2.8	0.4	4.8	13	7	98
S12	26	33	2.7	0.8	3.2	13	4	96
S13	23	38	2.9	0.6	4.8	10	5	96
S14	23	29	2.9	1.1	3.7	9	9	96
S15	28	35	2.8	0.2	3.8	13	6	96

Table 4. Pearson Correlation Matrix of Engineering Tests of Dolerites of Kirana Aggregates

	Flakiness	Elongation	Specific Gravity	Water Absorptions	Soundness	Los Angeles	Aggregate Crushing	Adhesion
Flakiness	1.00							
Elongation	0.16	1.00						
Specific Gravity	-0.40	0.53	1.00					
Water Absorptions	-0.13	-0.20	0.11	1.00				
Soundness	0.27	0.11	-0.01	0.18	1.00			
Los Angeles	-0.01	0.04	-0.16	0.09	0.23	1.00		
Aggregate Crushing	-0.66	-0.37	0.37	0.32	-0.04	0.34	1.00	
Adhesion	-0.08	-0.05	-0.22	-0.01	0.39	0.47	0.25	1.00

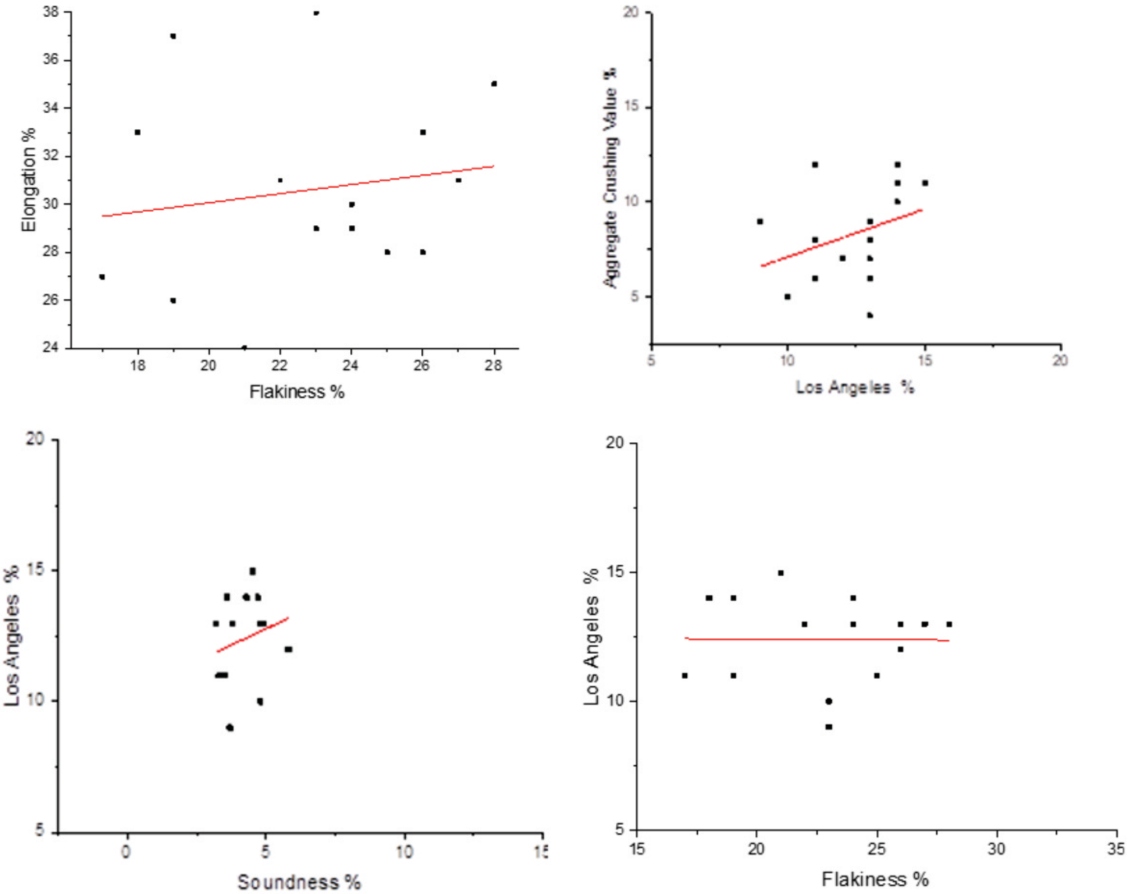

Fig. 4. Relation between elongation and flakiness

4. Conclusions

Dolerites are an excellent source of crush rock aggregates and satisfy engineering and petrographic properties for its use in bitumen concrete, wearing course and for cement concrete. This is the only rock type in the Punjab province for use in wearing course since it imparts excellent road grip and resists polishing (unpublished reports). This is the only suitable rock for bitumen concrete in the central Punjab (unpublished reports) and therefore its use must be restricted to cement concrete, asphalt base and wearing course, while rhyolites, volcanogenic slates, quartz wackes and lithic greywackes (which also occur in Kirana Hills) can be used as unbound base course and sub-base.

4.1. Recommendations

The aggregates produced at present in jaw crushers are flaky and elongated. Double stage crushing and use of the gyratory technique in crushing should be used to reduce flakiness and elongation.

For sub base and base course, the last and the uppermost layer must be of dolerite aggregate filled by fines (khaka) of the same material and subjected to prime coat followed by asphalt dressing or asphalt concrete.

Rhyolites, quartz wackes, volcanogenic slates and lithic greywackes (which also occur in Kirana Hills) should be utilized as riprap and railway ballast materials. It is observed that hard and heavy boulders of dolerites are also used as riprap because the crushers and plants sometimes cannot break these due to the low-quality crushing system. This practice should be avoided and heavy boulders must be broken by hand or machine and utilized for crushing which will help in the improvement of the quality of aggregates produced and in the production of ultra-strong materials for high strength concrete.

Author's Contribution

Muhammad Nawaz Chaudhry proposed the main concept and involved in write up. Muhammad Nawaz Chaudry and Muzaffar

Majid carried out laboratory work. Muhammad Nawaz Chaudhry and Muzaffar Majid, collected field data. Uzma Ashraf was involved in statistical analysis and help in laboratory work. All authors did technical review before submission.

References

Alam, G.S., 1987. Geology of Kirana Hills, District Sargodha Punjab 1 Pakistan GSP., Quetta Pakistan, 2 (1),1-37.

Alam, G.S., Jaleel, A., Ahmad, R., 1992. Geology of the Kirana Area, District Sargodha, Punjab. Pakistan. Acta Mineralogica Pakistanica, 6, 93-100.

American Society for Testing Material C 4791.Standard Test Method for flakiness and elongation in coarse aggregate.

American Society for Testing Materials C 128-93. Test Method for specific gravity and water absorption of coarse aggregate.

American Society for Testing Materials C 295-85 1985. Standard Practice for Petrographic

Examination of Aggregate for Concrete. Annual Book of ASTM Standards ASTM, Concrete and Mineral Aggregates, Section 4, C-295-85, 4(2), 221-232.

American Society for Testing Materials C 33-90, 1989. Test Method for Los Angeles of coarse aggregate.

American Society for Testing Materials C 3665-99. Test Method for random sampling of construction material.

American Society for Testing Materials C 88-90, 1989. Test Method for Soundness of Aggregates by Use of Sodium Sulfate.

Bhushan, S.K., 1999. Neoproterozoic Magmatism in Rajasthan; Proc. Seminar on Geology of Rajasthan: Status and Perspective, MLS University Udaipur, 101-110.

British Standard Institution BS 5750: Quality Assurance.

British Standard Institution BS 812 Part 110: Testing aggregates for aggregate

British Standard Institution BS 812 Part 112: Testing aggregates for aggregate

Chaudhry, M.N., Ahmed, S.A., Mateen, A., 1999. Some postulates on the tectonomagmatism, tectonostratigraphy and economic potential of Kirana-Malani-Basin Indo-Pakistan, Pakistan Journal of Hydrocarbon Research, Islamabad, Pakistan, 11, 52-68.

Chaudhry, M.N., Khan, Z.K., 1993. Engineering Geological mapping and quarry development for sub-base and base concrete. Unpublished Report for Daewoo Pvt., Ltd.

crushing value.

Dhir, R.K., Ramsay, D.M., Balfour, N., 1997. A study of the aggregate impact and crushing value tests, Journal of the Institute of Highway Engineers, 17-27.

Dolan, P., Edgar, D.C., Sherlin, B.J., 1987. Pakistan, regional geology and petroleum exploration potential-dolan and associates, non exclusive report, London. Fookes, P.G., Gourley, C.S., Ohkere, C., 1988. Rock Weathering in Engineering Time. The Quarterly Journal of Engineering Geology, British, 21,45-78.

Hussain, S., Khan, M. A., 2017. CPEC; A Roadmap of Region's Development. FWU Journal of Social Scieces, 11(2), 51-59.

Jamieson, I.L., Mouthrop, J.S., Jones, D.R., 1995. SHRP Results on binder aggregate adhesion and resistance to stripping, asphalt yearbook 1995, Institute of Asphalt Technology, United Kingdom.

Kandhal, P. S., Parker, F., 1998. Aggregate tests related to asphalt concrete performance in pavements, Research Report 405, National Cooperative Highway Research Program, National Research Council, Washington, DC.

Khan, Z. K., 2000. Study of the Geology of Kirana group, Central Punjab and evaluation of its utilization and economic potential as aggregate, Ph. D. Thesis, Institute of Geology, University of the Punjab, Lahore, 1-209.

Khan, Z. K., Chaudhry, M.N., 1991. Engineering, geological and petrographic evaluation of metadolerites of Buland Hills and Chak 123 Quarries of Kirana Hills, district, Sargodha, Pakistan, Kashmir Journal of Geology, 8-9, 181-184.

Kochhar, N., 1998. Malani igneous suite of rocks, Journal of Geological Society, India, 51, 1-120.

Kochhar, N., 1999. A comparative study of the Malani Representatives of the Tusham Hills (Haryana, India) and Kirana Hills (Pakistan), Proc. 3rd South Asia

Geological Congress, Lahore, Pakistan.

Kochhar, N., 2000. Attributes and significance of the A-type Malani magmatism, Northernwestern Penisular India., In: M. Deb (Ed), Crustal Evolution and Metallogeny in the Northwestern Indian Shield. New Delhi, 515, 158-188.

Kochhar, N., 1984. Malani igneous suite: hotspot magmatism and cratonization of the Northern Part of Indian Sheild. Journal of Geological Survey of India, 25 (3), 5-161.

Lees, G., Salehi, M., 1967. Orientation of particles with special reference to bituminous paving materials. National Academy for Science and Natural Resources Council, Highway Research Record, 272, 63-75.

Mielenz, R.C., 1994. Petrographic evaluation of concrete aggregates, In American Society of Testing and Materials, Concrete and Concrete-Making Materials. ASTM International.

Neville, A.M. 1981. Properties of Aggregates, Pitman Book Limited.

Neville, A.M., 2000. Properties of Concrete. Pearson Education Asia Ltd. Edinburgh U.K., 4th ed., 844.

Robertson, R.E., 2000. Transportation research circular 499, chemical properties of asphalts and their effects on pavement performance, TRB, National Research Council.

Shah, S.M.I., 1977. Stratigraphy of Pakistan, Geological Survey of Pakistan, Memoir, 12: 138.

Shah, S.M.I., 1973. Occurrence of gold in the Kirana group, Sargodha (Punjab), Pakistan, Inform Release, Geological Survey of Survey, Quetta, Pakistan, 68, 1-14.

Smith, M.R., Collis, L., 1993 Aggregates — sand, gravel and crushed rock aggregates for construction purposes, The Geological Society, London, 2nd ed., 199-224.

Terrel, R.L., Shute, J.W., 1989. Summary report on water sensitivity, SHRP-A/IR 89-003.