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D03776

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.[illegible]
26 June 1972

ENGLISH

Interregional Seminar on the Manufacture
and Utilization of Portland Cement

7 - 20 May 1972
Holte, Denmark

AGGREGATE MATERIALS FOR CONCRETE PRODUCTION, NATURAL AND ARTIFICIAL 1/

by

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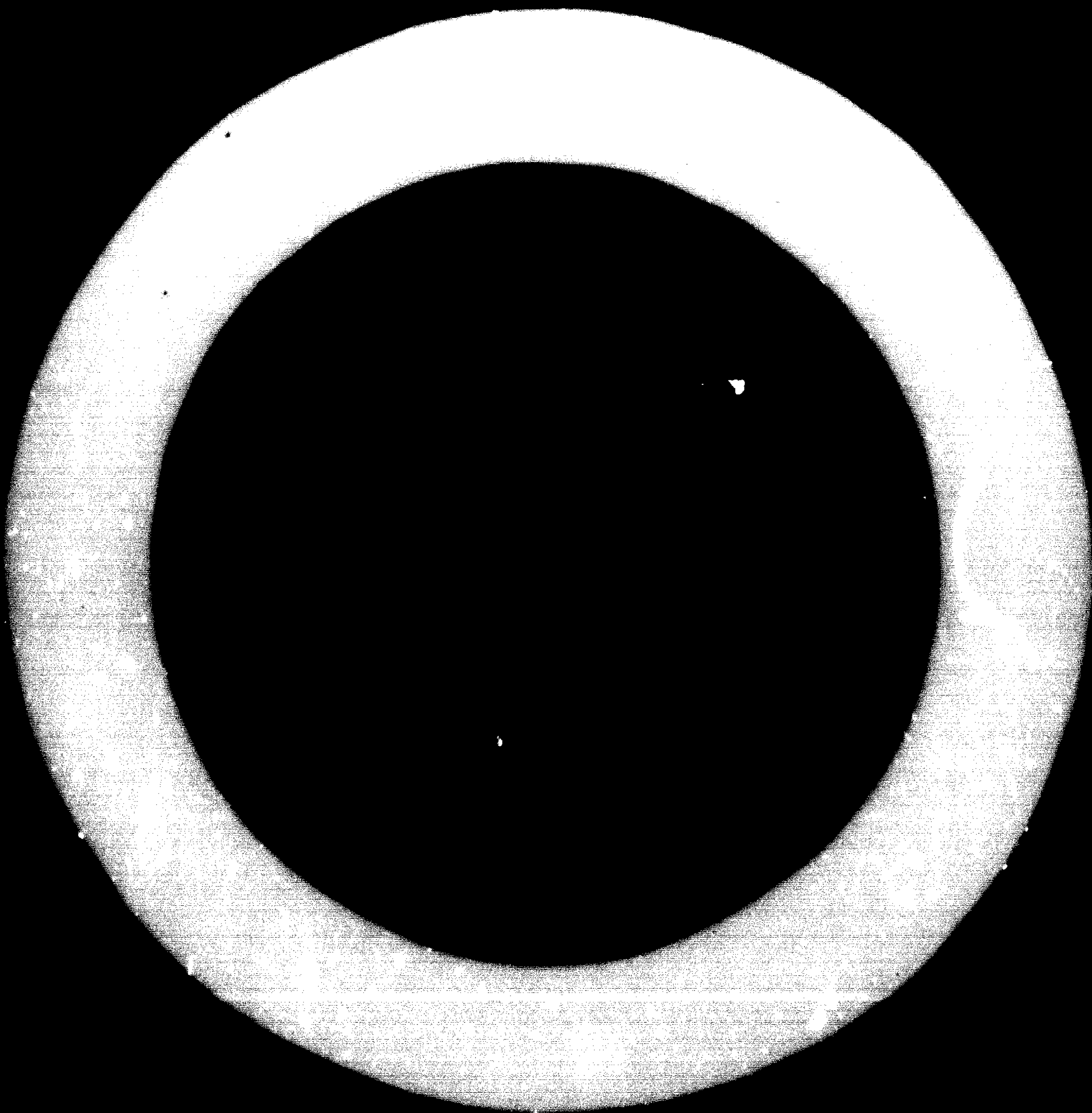

1. Introduction

Gravel in Denmark is essentially won from loose, sedimentary deposits, [illegible] a relatively modest production of crushed granite in Bornholm.

The formations worked is deposited during and after the quaternary glaciation. During this period Denmark was ice-covered 4 times, the glaciers bringing a lot of material from the Scandinavian peninsular. This was deposited at the time of melting of the glaciers.

The deposits are partly moraines, partly often characteristic melt-water deposits of a shape having made them easy to locate. Especially the melt-water deposits are worked. Probably there are no surface close deposits of this kind at which excavation of gravel has not taken place at one time or another.

The materials treated in this paper are classified according to a well-defined sieve-analysis. Thus sand is defined as grains being able to pass a 4 mm ☐sieve, stones are retained on a 4 mm sieve, and gravel is a mixture of sand and stones.

Seen from a production-point of view aggregate materials are divided into "hill materials" won by production on land, sea dredged materials pumped from the sea or taken on the beach and rock materials produced by crushing bedrock.

Petrographically Danish aggregate materials consist of a mixture of Scandinavian bedrock and minerals and material from our own underground.

Thus the composition of sand [illegible] is about 70 - 80% quartz, 2 - [illegible] feldspar, [illegible] calcite, furthermore very few other minerals and [illegible] amounts of clay.

The stone material [illegible] [illegible] [illegible]ally [illegible] the country as a function of the deposition history and the weathering after deposition. Typically in the eastern part of Denmark all gravel types are rich in flint and limestone and only contain about 20% of granite. Going to the west the amount of flint and limestone is decreasing because the pre-quaternary underground is clay-rich, tertiary rocks, while in East Denmark it is flint-carrying cretaceous limestones. In the western part of Jutland the gravel types are rich in flint because weathering effectively has removed limestones and crystalline granites and gneisses. There is still a good amount of quartzites left. Except for certain types of flint and limestone all the stone material effectively are sound regarding physical and chemical properties, although precautions have to be taken to avoid pop-outs during freezing.

Artificial aggregates in the form of expanded clay is produced in rather big amounts in Denmark. These are to some extent used in construction concrete although the major use is in prefabricated wall panels and building blocks, and as loose insulating material.

Artificial aggregates can also be produced by sintering p.f.a., this is, however, not done in Denmark.

2. <u>The Function of Aggregate in Concrete</u>

Previously the aggregate has been considered an inactive filler usually accounting for 70 - 75% by volume of the concrete mass, and compared to the cement rather cheap. This point of view has gradually been modified and it is now generally realized that a lot of the properties in fresh as well as hardened concrete are intimately connected with the properties of the aggregate. In particular a series of destruction mechanisms can be ascribed to reactions between cement paste and aggregate. Thus it is not immaterial which kind of aggregate is chosen, and the following considerations will mainly deal with the function of the aggregate in concrete, and which demands reasonably can be required to ascertain the properties of the concrete in the period of function. In the fresh concrete particularly grading and grain shape have substantial influence on the workability, water requirement and stability.

The gravel is normally the cheapest component in concrete, and it is therefore the aim to make this amount to as great a part of the concrete as the other demands will permit (e.g. the form of the reinforcement etc.). This means that it is endeavoured to build up a grading having least possible porosity. Suppose the curve is being built up gradually beginning with the biggest grains in the gravel. The space between these are filled with somewhat smaller grains, the size and amount adjusted in such a way that the holes are filled in the best possible way. After this even smaller grains are added and so on until the smallest size in the gravel. The remaining space is finally filled up with cement paste. A grading built up to this principle will in theory be excellent and economic. In practice the resulting concrete will require larger amounts of compressing energy to obtain suitable quality after casting. Looking at the mechanism in compression one will realize that the small grains and the cement paste will act as a kind of ball bearings between the larger grains, the resistance of these to obtain a closer spacing depends on their shape and surface characteristics. The factors have to be evaluated until deciding the amount of sand necessary in a given mix. For example it is obvious that crushed grains will require more sand than well rounded grains. In relation to workability the percentage of sand essentially is the only parameter to be chosen freely.

It has been mentioned that the small particles, the sand and cement, are urgent factors in reduction of the internal friction in the concrete. Cement-rich mixes, therefore, will allow lower percentage of sand. Since the specific surface of the sand has a great influence on the water demand it is not unimportant which sand is chosen. At least in theory the sand to be chosen will be the one giving the wanted workability using least water.

The content of filler in sand (this being grains < 0.275 mm) has great influence on the stability of the concrete. Because of large specific surface filler is strongly waterrequiring and therefore will counteract the tendency to bleeding. On the other hand a large content of filler will require much water, and in practical life one will have to choose a suitable compromise. If air entraining agents are added the filler content can be reduced since the air-bubbles between the gravel grains will prevent water to be pressed out. Making of water-proof concrete requires in general a v/c ≤ 0.60 and a content of cement plus filler < 0.25 mm in excess of 375 kg/m^3 concrete.

The figure added in the end of the paper suggest a grading of the aggregate mix. If the sand curve is between curve A and B, and if the gravel curve reminds of curve C and not departs essentially from curve C, it will normally be ascertained that separation of concrete during casting and transport can be prevented. The concrete will be suitable to vibration.

It is the hope of the author that these considerations will show that "ideal" curves for gravel can not be given.

Also in the hardened concrete the aggregate is strongly influencing a long row of properties, e.g. strength, elasticity, drying shrinkage and durability. The bulk density can be guided by choice of light or heavy aggregates.

In ordinary concrete the strength is essentially a function of the v/c ratio and the amount of the cement, although it seems to be proven that in concretes having same v/c ratio the strength will decrease with rising maximum grain size in the aggregate. Of course the strength will also to a certain extent be depending on the adhesion between mortar and stones, this adhesion being essentially physical in nature. If e.g. the stones are covered by a layer of clay at the surface, the adhesion will be very bad and smooth grains are not adhering as well as rough grains. A problem to be looked after in the sand is organic impurities, e.g. humic acids. These will retard or prevent the binding of the cement and can make the sand unusable. Humic acids can often be removed by washing of the sand.

In the preceding sections the role of the grading in the fresh concrete has been mentioned. In the hardened concrete the grading has influence in limiting the drying shrinkage since only the binder is shrinking. A dense skeleton of grains will prevent shrinkage deformations and will to a certain extent be able to absorb the resulting strain.

The petrographic composition of the aggregates plays an important role in the durability of the concrete. This point has to be divided into two subpoints since the concrete has to be durable against physical attack and also has to be resistant to chemical destruction by reactions between cement paste and aggregate. Of course the reinforcement must not be exposed to corrosion either and is not supposing the concrete is kept intact without fractures, and supposing the concrete layer above the reinforcement is sufficiently thick. If a few limitations in the v/c ratio are accepted the physical durability of the concrete will essentially be a question of the durability of the aggregate against physical attacks. This is essentially a question of resistance to freezing under our climatic conditions. In this respect only hard and dense stones can be considered good, since porous grains close to the surface can be water saturated and by freezing give rise to pop-outs. These damages allow further erosion in these places and have to be prevented. Particularly, and so far not fully researched problems are raised looking at the durability of concrete against thawing chemicals. The chemical resistance must be ascertained by choice of aggregate not containing weathering particles, e.g. pyrite, and not being reactive together with the cement paste.

Certain rock types will react chemically with the alkalies in the cement and form expanding gels by adsorption of water. The reaction is believed in principle to follow the scheme below:

$$SiO_2 + NaOH + Ca(OH)_2 + H_2O \rightarrow$$

$$n_1 Na_2O \cdot n_2 CaO \cdot n_3 SiO_2 \cdot n_4 H_2O,$$

Na_2O being equivalent to $Na_2O + 0.66\ K_2O$.

Gels being able to expand more than 200% have been noticed, and it is obvious that this can give rise to serious damage.

Those minerals and rocks being able to react with cement are SiO_2-rich like:

Opal, Calsedony, Christobalite,
Rhyolite, Andesite, Phyllites, Slates, Flint and Churt.

The following very general considerations can be done: <u>The amount</u> of reacting aggregate is urgent. A certain value has to be exceeded until the expansion is injurious. On the other hand a great amount of reactive particles quickly will reduce the concentration of alkalies thus stopping the reaction.

<u>The size</u> of the reactive aggregate is another urgent factor. Small grains will cause a total reaction whereby gels are formed. Thus the alkali concentration is reduced and therefore gels will not be formed around the larger grains where the reaction is dangerous. This is explaining why particularly the medium big or big grains of reactive aggregate will cause damages if reactive sand is missing.

<u>The alkali-concentration</u> is the primary factor in the reaction. The concentration is depending on the content of alkalies in the cement, the amount of alkalies liberated from the surroundings, e.g. sea-water or weathering of felspars. Furthermore the alkali concentration in the mixing water.

The consequences of alkali-silica reactions are the following, the effect of which can be superimposed:

a) Extreme expansion and deformation.
b) Formation of cracks, the direction of which is not in accordance with the local stress system.
c) Formation of conical pop outs.
d) Precipitation of gels at the surface.

Precautions against these reactions can be obtained in various ways:

Using common aggregates together with alkali-poor cement.

Using common aggregate plus ordinary cement plus pozzolan.

Using ordinary Portland cement together with not reactive aggregate.

Usually the method last mentioned is the most expensive but also the only one being absolutely safe. It is not to be forgotten, however, that related reactions can happen without formation of expanding gels. In that case the binding between the cement paste and the aggregate becomes chemical in nature thus giving very good adhesion between mortar and stones. This is said to be happening if CaO is in great excess to the reactive silica and alkalies.

3. <u>Danish standards</u>

Requirements for aggregates for concrete being valid at the present time is published in DS 411 together with testing methods for demonstration of the suitability of the aggregates. This standard is pretty old and is under revision. The main part of the new specifications are published in proof.

Valid requirements give limitations in the content of clay, silt, calcite and organic impurities. In the new standard is not given petrographical limitations but only limitations in the content of disintegrating and porous grains. Limitations in the chemical compositions are not given.

The test methods applied in this country are in general in accordance with ASTM methods, adjusted according to units.

4. Production

Unfortunately it is not possible to giv general rules for production [illegible] the investments necessary since the plant for production of aggregates to a high extent has to be designed to meet the special problems raised by the raw material and the local geology, e.g. the ground-water table. Furthermore the need for investments will to a high extent be connected to the wanted capacity of the plant.

Knowing the raw material and the wanted capacity, it is possible to buy prefabricated plants being able to meet the requirements. Information of these can to a high extent be gained from the literature e.g. "Rock Products".

Our experience is in general that it is profitable to design and build the plant ourselves, although we frequently make use of certain prefabricated components.

Certain types of equipment is absolutely necessary, this being: Gear for excavating the raw material, for internal transportation, for working of the raw material into the commercial product. Stock-pile and lorry loading equipment is also necessary. At the plant at least screens and a certain amount of conveyors will be necessary, sometimes supplemented by washing of sand and stones, and sometimes also crushers will be required.

The following considerations will mainly be dealing with the description of various types of equipment and methods being used in Danish gravel pits. Unfortunately, the writer is not able to give detailed technical information on the various types of machinery, but at the excursion to the gravel pit at [illegible], the participants will meet our [illegible] engineer who will be able to answer more technical questions.

At the excursion the participants will see a modern Danish plant for production of among other things aggregates for concrete and the main principles in the production-flow will be demonstrated.

The plant is rather untypical since it is among the biggest in the world, having a capacity of more than 2 million cubic meters per year. The article included at the end of this paper briefly describes the production-flow and corresponds to the facts to-day except that the internal transportation to a high extent has been changed and modernized.

Danish gravel deposits are in general covered by overburden, which has to be removed. At Nymolle this is done by using two 1.5 m^3 excavators, and the overburden is carried away using lorries and conveyor. The overburden is removed continuously and is dumped in already excavated parts of the pit.

Elsewhere the overburden is removed occasionally using excavators, pay-loaders or dozers. Furthermore it has proved to be profitable utilizing contractors' supplies in periods when it is not occupied at construction work. At the moment we are planning to get a walking dragline for removal of overburden.

In general it is economically sound to remove the overburden, if the ratio gravel/overburden exceeds 2.

The gravel is excavated utilizing the same types of equipment as mentioned above. Often only the material above the ground-water table is utilized, but certain places also gravel from below the ground-water is dug using specially designed equipment.

The internal transport from the face to the plant is carried out in various ways. Usually is used either lorries or dumpers, here and there dumping waggons.

The trains are rather labour requiring since a certain amount of people are occupied constantly with moving tracks. Transport by conveyors is an economically good solution since it can be placed permanently and only needs to be extended in sections. At the beginning of the conveyor it will often be necessary to have a large crusher to diminish the wear on the conveyor, or the larger boulders have to be taken away otherwise. At Nymølle boulders larger than 600 mm are taken away, the rest being crushed to less than 250 mm.

At the plant the gravel is split up by screening into the common commercial products, the screening being performed at different levels. Certain fractions are after the screening mixed in well defined proportions to meet given specifications. In general about 10% of oversize is accepted, and from a capacity point of view the screening is often performed using screens having larger size than the description indicates. For example 0/8 gravel is produced using a 10 mm screen.

Since the requirements of the Danish market for small stones, particularly 8/16 mm, is larger than the production of natural stones, crushing is used at different levels. After crushing the crushed product is recirculated in the plant to be mixed with the rounded stones from the deposits. Thus at Nymølle is used about 15 crushers at different levels in the process, among others in a separate plant producing only crushed products sorted in the same fractions as the usual aggregates.

Crushing is performed using either jaw crushers or cone crushers. From our experience jaw crushers are best suited for crushing larger boulders, and cone crushers the best for the smaller fractions, less than [illegible] mm. If running the [illegible] overloaded the internal friction between the stones [illegible] reduce the wear on the jaws, since only a smaller fraction of the stones actually has to be crushed between the jaws.

Stones for concrete aggregate, derived from sedimentary deposits often need washing before being used to ascertain that dirt and clay on the surface are removed. There is a large selection of various scrubbers commercially available.

At Nymolle gravel pit we have found that only sluicing at the screens are required to remove unwanted clay, but elsewhere we are using scrubbers of the counter-flow type. The waste water*is led to a sand tank, where the sand is sedimentated and taken out to become dewatered either at dewatering screens or in double screw washers. From the overflow of the sand tank a certain amount of fines is concentrated in hydrocyclones. The water still containing a certain amount of fines is led to a basin for purification and is thereafter recirculated in the plant.

Washing of sand can be necessary to remove clay and humic acids. Usually the goal is reached after washing, at least if the sand is left in stockpiles for dewatering.

To meet the requirements of the Danish Standards as to the content of porous stones, sorting of the stones can take place. This is so far in Denmark done by hand-picking, automatic machines not yet being used. Stones larger than 70 mm is usually chosen since the fraction 70/250 mm gives the largest output per man per day. Going down in size the capacity is going radically down for obvious [illegible]. Going up in size, the capacity is dropping [illegible] the stones become too heavy to handle. At [illegible] the [illegible]ite and [illegible] stones are removed.

The sorting can be performed on either washed or unwashed stones. The stones are passing the pickers at a conveyor and they dump limestone and granite directly into silos. The granites are crushed and fractionated for aggregate. The limestone is used for other purposes. The remaining product after removal of granite and limestome is sufficiently low in porous stones to meet the specifications. It is very rich in flint and is taken to a separate plant, where it is crushed and fractionated to aggregate.

Frequently the screening plants are placed at the top of the silos from where loading direct into the lorries can take place. Stockpiling at the ground takes often place, the stockpile being built up when the silos become full. In this case loading is performed by pay-loaders. Selling is usually by volume, although the more modern plants are selling by weight. Thus at Nymølle we are equipped with three 50 ts weights each 3 x 20 m having capacity to serve about 5 lorries per minute.

5. Testing and Quality Control

The aim of the producer f aggregates f r concrete - running quality control - is to ascertain a production being as uniform as possible. The considerations in the preceding sections should show that good concrete can be made from a wide variety of raw materials. However, it is very important in the production of quality concrete to make sure that the applied materials are as uniform as possible, and as a matter of fact this is one of the most essential but also the most difficult things for the producer of aggregates to reach, particularly within the economic limits given.

The methods generally applied in quality control are in accordance with ASTM methods and must be adjusted and illustrated in such a way as to show vhether the products stay within the accepted quality limits.

Testing and control will in general have to be performed on representative samples of aggregate. The sampling procedure must therefore be planned in such a way that the resulting sample is repiesentative and this is only possible if the bulk material is homogeneous. If the stockpile is large one will get problems in sampling the center of the pile.

In practical life at least 6 samples are collected from the bulk. The necessary size of the samples is essentially a function of the maximum grain size as shown in the table below:

Max. grain size mm □	Necessary sample size, kg
2	0.2
4	0.4
8	[illegible]
16	3.0
32	10.0
64	40.0

The table is in accordance with suggested Danish Stand rds.

At the laboratory the samples taken are thoroughly mixed and homogenized and divided into 1 sample supposed to be representative of the bulk material. This sample is used in the various types of testing being wanted.

The testing methods applied in testing of aggregates can be divided into three main groups, each characterized by the way in which the testing is performed and each group showing different statistical problems in treating the results. In general one will have to ascertain that published test results are statistically sound. Every result ought to be followed by statistical limits.

The way of dividing test methods is as follows:

I. The sample treated is split up in smaller samples not consisting of single grains. Examples are sieve-analysis and all sorts of sedimentation analyses. The accuracy of these testings essentially is a function of the weight of the sample, and samples smaller than the minimum size given in the table are not worth treating.

II. The sample treated is split up in smaller samples after observations of the single grains. Examples are all determinations of petrographic composition, determination of grain shape, roundness, structure and hardness, surface characteristics. The necessary sample size is essentially a function of the number of grains inspected.

III. The sample is treated in bulk. Examples are determination of bulk density, specific gravity, water content, content of humic acids etc. The necessary size corresponds to the size of the methods in group I.

Expression of the results obtained will generally require some sort of illustration to make comparison easier. The methods in group I generally result in a row of numbers, these numbers being correlated because of the methods applied. Statistical treatment of those therefore are at best extremely difficult.

The methods in group II can be illustrated either diagramatically or schematic. The statistics connected to these procedures are straight forward once the number of grains is known. Usually these methods are only applied to grains > 4 mm. Of course it is possible to examine smaller grains also, but the conclusions to be drawn from analysis of the stones are more straight forward than the conclusions to be reached after treating sand according to the same principles.

The methods in group III generally are expressed as a single number. There are no problems connected with the statistical treatment of these.

The detailed planning of the quality control has to include definition of the terms at which the different products have to be test d. Thus at our firm the most sold fractions are tested daily, others are tested only occasionally.

In this country only road metal has to be tested regularly according to Danish Standards requiring one sieve analysis after production of each 500 m^3 at least one analysis per day.

6. Commodities

Our company is producing 29 different sand and gravel products at three different pits, the major one being Nymolle Stone Industries. The products are graded according to a mm scale measured in square holes. Sand is sold, washed or unwashed, graded 0/2 washed, 0/4 washed, 0/4 unwashed, 0/8 unwashed, 1/4 washed. Stones are sold, washed and mainly naturally rounded in the following gradings: 4/8 mm, 8/16 mm, 16/32 mm. Unwashed stones are graded: 32/48 mm, 32/60 mm, 70/100 mm, 100/250 mm and 250/600 mm.

Crushed and mineral sorted aggregates are produced as follows:

Granite: 6/10 mm, 10/20 mm, 20/32 mm, 32/48 mm, 32/60 mm.
Flint: 0/2 mm, 2/8 mm, 8/15 mm, 16/32 mm, 32/64 mm.
Unsorted, crushed: 32/50 mm.

Furthermore we are producing road metal in the following fractions: 0/16 mm, 0/22 mm, 0/32 mm, 0/50 mm, 0/100 mm.

Finally we are selling various types of unprocessed gravels taken direct from the face.

Our total production amounts to 3 million cubic meters per year.

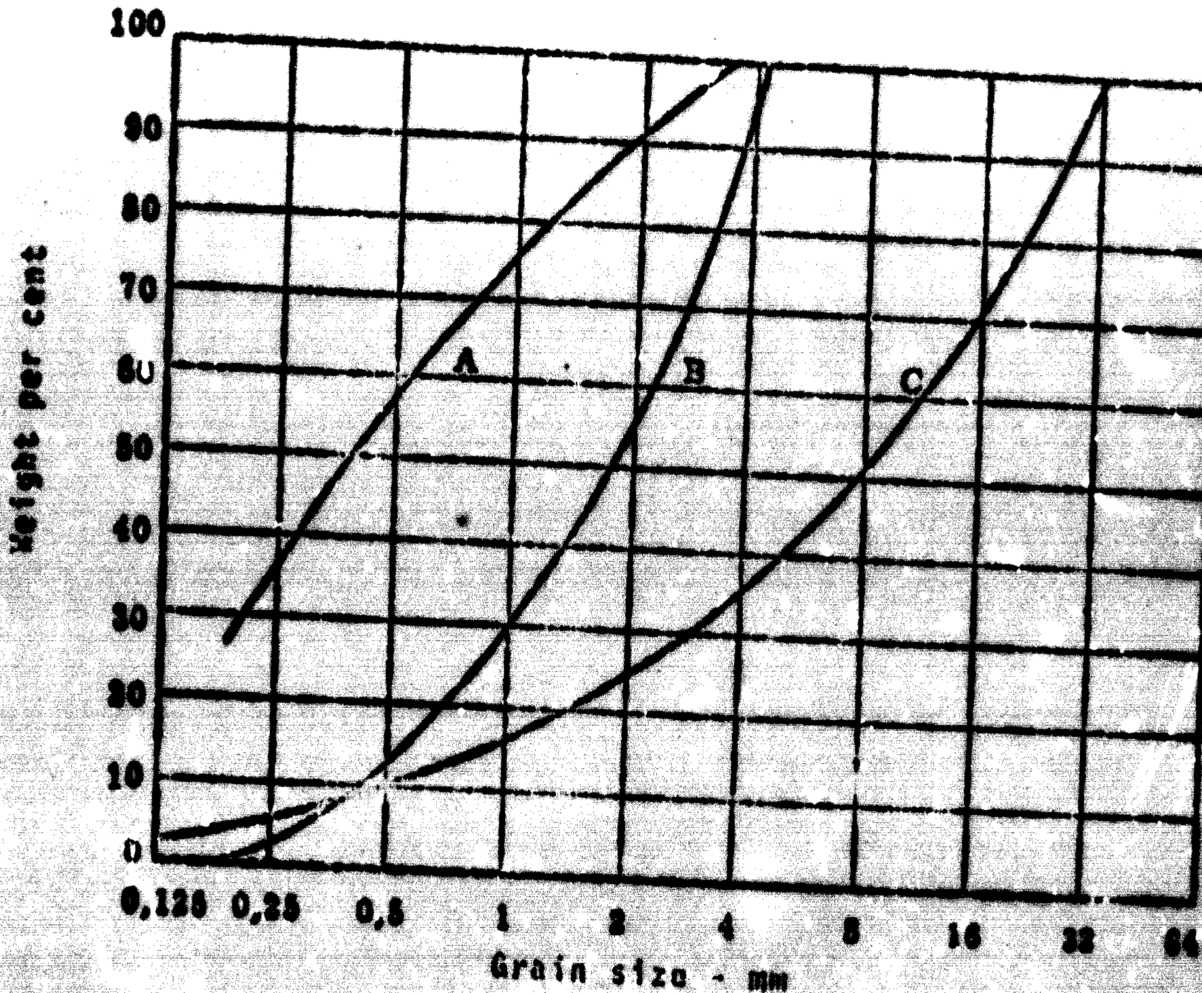

Figure showing grading of aggregate.
Reference: Page 4 and 5.

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