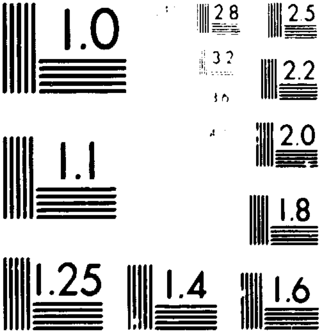

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PERLITE AND ITS INDUSTRIAL USES

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1. INTRODUCTION

This paper collect research results and industrial experiences obtained in Hungary and abroad concerning geology, mining and crushing-grading of perlite, its expansion, industrial and agricultural uses, or more exactly all possible uses of perlite. It is based on the book "Perlite Concrete - Perlite Mortar" by Dr. János Ujhelyi published in Hungary /Müszaki Kiadó, Budapest, 1965/ but this study is more detailed and covers achievements, industrial experiences obtained in the last 17 years.

Perlite is a volcanic glass of high water content, finely crushed and roasted at 800 to 1100 °C. Upon heat effect, tiny particles expand to the multiple of their original volume.

USA were the first in the industrial applying perlite by the early 'fourties /1/. It soon became popular, wanted in the building industry owing to its extremely light weight and good thermal insulation. It is among the lightest of the actually known porous aggregates, a fact defining its field of use.

It is mostly applied as aggregate for mortar and concrete to provide for thermal insulation and light weight of buildings. Recently, however, its peculiarities extend its field of use: its great specific area recommend it for filtering, heat and fire resistance for insulating industrial furnaces, district heating pipelines, high water retention in agriculture /e.g. for soil exchange, plant breeding etc./.

Almost everywhere, industrial use preceded systematic, purposeful research-testing work, testifying utility of the material on one hand, but leading to controversial experiences because of insufficiently known material properties and undeveloped processing technologies.

These opposed themselves to the early extension of perlite.

Perlite industry undergoes a mighty development throughout the world. As against 17 perlite factories in the USA in 1949, by 1971 87 of them were in operation, processing about 350000 tons of perlite a year. In the USSR perlite research and use began about simultaneously, by the second half of the 'fifties to produce some 1 million cu.m of expanded perlite by 1970. Several countries in Europe and overseas have large-scale, booming perlite industries /England, Bulgaria, Czechoslovakia, Greece, Federal Republic of Germany, Iceland, Japan, Italy, etc./. In Hungary, use of perlite started in 1958 /2/.

Perlite fines /0 to 3 mm/ are used in the building industry mainly for thermal insulation, as loose upfill or mixed with binders in cast in-situ and prefabricated concrete, mortar. Many data refer to its use in insulation casing of district heating pipeline, refractory concrete, in concrete for a wide range of building uses /garages, bungalows, site buildings, power station switchboxes etc./, for stiffening concrete, acoustic linings, etc. There are some examples for its structural uses as concrete aggregates for roof slabs, partitions, external walls, although for this latter, larger expanded perlite particles are preferred /D_{max} = 15 to 30 mm/. Raw perlite can be mentioned as prime material for ceramic paints, glazing and glass /3/. Latent hydraulic properties of given types make them a concrete admixture /4/.

In the building industry, primarily the extension of new building systems laid claim for cheap, simply producible, high grade thermal insulations. Namely in up-to-date architecture, in order to decrease building weights. Different materials are applied for load bearing, thermal insulation, sounddamping, fireproofing, etc.

All these tasks were traditionally achieved by brick; strength of a 38 cm brick wall met requirements for multistorey buildings, thermal and acoustic insulation were adequate, nice brick façades could be made with selected bricks, frost resistance, fire resistance and durability were sufficient.

Advent of building industrialization, assembly methods required both possibly large-size and high-strength, and at the same time, possibly light-weight building units /walls and floors/. These requirements could not be met by a single building material /brick/, it was replaced initially by reinforced concrete, later by steel for load bearing, heat insulation was provided by hollow brick, lightweight concrete, and quite recently, by synthetic materials. Heat and fire resistance of these latter is still problematic, and manufacture is rather power consuming.

The recent building systems are accompanied by technological requirements. Units for industrialized mass building must be produced in large series, at a high-grade mechanization and automatization, weather-independent, perfectly eliminating finishing sitework, at a high productivity. Part of these requirements can be met by the use of perlite.

Besides of building industry, also other industries lay claim on perlite. Chemical industry applies perlite as filler, catalyst, pigment carrier, as well as filter aid, a use common with food industry /in sugar and beer production as filtering perlite/ in addition to being used for packaging because of chemical inertness. In siderurgy it is applied for keeping steel hot after founding, in the mechanical industry for vibration damper. Agriculture makes use of perlite water retention for soil exchange, plant breeding, garden soil amelioration, while water management applies perlite for reducing stillwater /e.g. lake/ evaporation.

Perlite has a special importance in environmental engineering, its high specific surface enabling it to neutralize water pollution /e.g. oil pollution/, indust-rial sewages, etc.

Versatility of perlite imposes systematisation, impeded, however, by contradictory test data obtained in each field of use including building industry, and in practical observations. On the other hand, great perlite consumer countries have published numerous reports on manufacture and properties that help orienting in the chaos of booklets, inventions and inconsiderate attempts.

2. OUTLINES OF THE GEOLOGY OF PERLITE

The industrial value and lithological character of perlite was not recognised until the middle of this century. In geological papers published in the 19th century and in the first decades of the 20th as well we may find mentions only of "glassy rhyolite" and "perlitic rhyolite".

From the industrial point of view we may describe as perlite "any vitric volcanic product with sufficient water content /usually over 2%/ to cause it expand to a utilisable light weight material when heated under controlled conditions".

The geological determination of perlite is bound to more strict conditions. We must not regard -for example - some expandable volcanic tuffs /pumicite/ or lava rocks as perlites. For sake of uniformity it is expedient to use this rock name in the sense of geological determination.

Geologically we may describe the rock consisting essentially of volcanic glass as perlite which

- takes its origin from a lava of strictly determined chemical composition and water content
- consolides under determined physical conditions
- and has the ability of expanding from 10 up to 20 times of original volume in the course of heating in kilns.

The average amount of siliciumdioxide /SiO_2/ in the typical perlite is in the interval of 70-75 weight%, while that of the alumina is generally between 12-16 weight % of the rock mass.

The sodium and potassium content of perlite is of great impotance, the viscosity of lava being in proportonal relation with the amount of alcalines. The escape of volatiles, consisting mainly of water is prevented by the viscosity of the cooling lava. The same viscosity is yielding the possibility of the expansion of rock without disintegration into microscopic drops. The total amount a sodium and potassium /in oxides/ is about 6-9 weight % of the rock.

Other components of the perlite rock, the iron, the manganese, titan, phosphor and sulphur are present in very small quantities, and from the point of view of industrial utilization are negligible - somewhat greater amount of ironoxides however causes unwanted coloring of the products and that of the sulfuroxide has harmful sideeffects in kilns.

The most important component of perlite is the water bound to rock texture or "solved" in the volcanic glass - behaviour of which is a determining factor for industrial usability of rock.

The water in perlite rock is present in two forms.

The molecules of "textural water" /or "water of construction"/ are set among the silicate tetrahedrons preventing in this way the composition of crystal structures i.e. these form of water contnet stabilizes the volcanic glass.

The other part of water content may be mentioned as "molecular water" /or zeolitic, free water/ which is concentrated in the submicroscopical or microscopical fissures of rock texture. It is easy to expel this part of water content from the rock.

There are a continuous interference between the two forms of water - the molecules of the latter are entering in the volcanic glass. This results a slow process of recrystallization.

The above described chemical composition is charac-teristic to acidic magmatic rocks /i.e. those consisting mainly of silicium dioxide/. By this way the perlite belongs to the group of rhyolitic-dacitic rocks or - in broader sense - in to the so called "pacific" or "calc-alcaline" province of magmatic rocks. It represents a specific "facies" /or rock type/ of these, which comes into being only under strictly determined circumstances. The striking uniformity of chemical and textural composition of perlites in a wide range of perlite deposits throughout the world is a reliable proof for this statement.

The mineralogical character of perlite rock can be shortly determined as "volcanic glass with some amount /up to 8-10 volume % / of crystallized minerals and other particles /e.g. obsidian fragments and needles/".

The characteristical figure for amount of glass is between 90-97 percent of volume, that for the minerals /crystallized fraction/ is between 3-10 vol.%. The bulk of mineral /crystallized/ fraction of the perlite is composed of feldspars /plagioclase/ and also the biotite is occuring often in places. Other minerals: quartz, apa-tite, magnetite are extremaly rare.

Most perlite are of grey colour the intensity of which varies between whitish, silver-grey and dark grey or black. Bluish or greenish shades of colour are frequent sometimes russet coloured types are occuring too.

A number of theories were composed concerning the formation of perlite. The well known facts or better to say, conditions of perlite formation are as follows:

The occurences of perlite are always confined to areas of volcanism, which yields rhyolite or rocks of rhyolitic--dacitic character.

The sudden cooling of lava which prevents the crys-tallization of the molten liquid is a precondition for perlite genesis.

During this process /i.e. the "freezing" of lava/ sufficient pressure needs to prevent the escape of water from the stiffening liquid.

The characteristic of the volcanic activity or more precisely to say those of the process of eruption period which make room for the formation of perlite deposits may be described shortly as follows.

During a relatively long period of standstill, the gases of the liquid lava attain a considerable grade of enrichment in the upper part of the volcanic channel. In the initial phase of eruption the pressure of gases breaks up the mass of older volcanites. With the sudden fall of pressure the lava column "boils up" and enormous masses of pumice will be ejected, mixed with rock fratments originating from sheets of former lava flows or pyroclastics. /The volcanic channel acts as a natural kiln for perlite expansion/.

By this way the first phase of eruption is of highly explosive character and produces thick complexes of pumiceous tuffs and pumice.

In deeper horizons of the lava column the liquid contains smaller amount of gases /and water/, while the pressure is bigger. During the rapid ascension of this lava the volatile /mainly water/ content has no possibly to escape from the liquid. It may intrude - extruding from the volcanic channel - into the tuffs and pumice series produced by the initial stage of eruption or cover the surface as lava-flow.

In the case of extrusion the cooling and consolidation of lava takes place under pressure. By this way liquids of high temperature /1000-1250 °C/ are turned into vitritic masses. This is the mechanism - in rough outlines - of the formation of the extrusive-type perlite deposits.

Supposing the weight of a 5 metre thick column of molten rock being equivalent to the pressure of 1 atmosphere, the cover which yields a sufficient pressure for perlite formation must be as the following table shows.

Temper- ature °C	Depths of formation for the phases /in metre/		
	pumice	pumice and glasses	glass
9000	on the surface	between 0- 5 m	under 5 m
950	above 10 m	between 10-40 m	under 40 m
1000	above 35 m	between 35-64 m	under 64 m
1050	above 51 m	between 51-70 m	under 70 m
1100	above 60 m	between 60-75 m	under 75 m
1150	above 65 m	between 65-80 m	under 80 m

The extrusion takes place mainly on the slopes of volcanic cones, in the immediate environment of the main volcanic channel. The perlite bodies formed by this way are of limited extension, up to several hundred metres in their horizontal dimensions and with an average thickness of 10-50 metres. The reserves, however, are adequate for mining on bigger scale.

In teh cross section of this deposit-type the perlite facies of inner parts, the transitional rock types and the "enveloping" breccia /or agglomerate/ are always distinguishable.

Lava-flows with lesser reserves of heat /temperature of the liquid about 900-950 °C/ may be consolidated into perlite under atmospheric pressure as well.

This is the case of the formation of the "lava-bank type" perlite deposits.

The "perlitized" lava-flows build up thick complexes - sometimes up to the thickness of 350 metres. In the complexes banks or layers of compact vitritic perlite are alternating with those of pumice banded perlite, lithophysic perlite or even bands or layers of rhyolite, representing the changes in water content, temperature and pressure conditions caused by subsequent lava flows in course of the eruption.

Perlite lava-agglomerates or lava breccias are occuring in these sequences always in great masses, for the younger lava flow breaks its way through the older ones. Both clastics and cement of agglomerates are of perlite - the latter being often pumiceous. In this deposite-type one can often see the transitional developing of the perlite into rhyolite as well.

According to changes of chemical composition and physical state of lava during the series of eruptions, a transitional development may take place between the above described deposit-types.

In the final stage of the volcanic activity the remaining lavas have only insignificant remains of their original water content. The last products of the eruption cycle are obsidian and rhyolite or some other acidic rock of the rhyolite-dacite group. Andesites are originating from the rest of the magma as well.

3. MINING GEOLOGY ASPECTS OF PERLITE

Macroscopically, perlites are distinguished by colour or texture, that is insufficient, however, for practical classification. Perlite kinds differ by morphology, strength and other properties /porosity, granularity etc./ Any of these properties may be applied for locally distinguishing types but these local distinctions are no commercial classification for perlite. There is no such significant difference between analysis data for different perlite types as to permit classification, differentiation between types.

Water contents are generally about equal, they are, however, of practically different expansivity, resulting from the bond strength of perlite crystal water and dehydration rate, besides of certain morphology peculiarities.

Thus, obviously, because of genetic features, perlite quality may vary greatly, at random, even within one site, along strike and dip, over a rather small area. Also dead rock beds have to be reckoned with, thus, quality determination should be based on frequent, careful mining-geology surveys. This randomlike quality change of perlite within a small area requires in any case a selective method of mining.

Because of its mineral components and texture, perlite has very abrasive properties, to be aware of both in mining, and in planning and operating the preparation plant.

Perlite is a brittle, cracked rock of variable texture, ready to crush in general. There are, however, also compact, high-strength perlite types. In mining this circumstances has to be kept in mind, since for the sake of possibly advantageous grading of the end product, the preparation plant require possibly coarse mining product.

All over the world, up to now, perlite is obtained from open pits, facilitating selective methods of mining perlite variable by quality at random, over small areas.

In general, to the expense of a relatively greater strip ratio, it is advisable to attempt open pit mining of perlite, even 1 to 3 strip ratio is admissible in perlite open pits.

Open pit mining permits optimum quality tests of mining geology prior to production - to cope with geological features of the site and the selected mining system. Thereby the maximum mineral yield can be obtained at the least production loss and minimum barren gangue handling. Production losses decisively depend on the mining method and the homogeneity of the product. Even in the open pit method. production loss generally amounts to 20 to 50 %. Part of it is due to dead rock interbedding that cannot be significantly altered. Similarly little influence can be exerted on losses due to dusting /coarseness/, however, strictly specifications for quarrying, material handling and for a careful grinding technology are observed.

In quarrying, requirements for selective production and careful material handling have to be kept in mind. Depending on the desired yearly output and material means, rock quarrying is advisably made at the least chipping possible.

General quarrying methods are either of the following three technologies:

- break-out with excavating equipment - with preliminary blasting
- drilling, blasting with manual loading
- drilling, blasting with mechanical blasting

Break-out with excavating equipment with preliminary blasting is the most expensive mining. It is rather energy-consuming, at the same time, however, it grants the best coarseness and the most careful material handling.

Mechanical break-out - loading equipment consists generally of baggers with ripping bailer, or in case of level deposits, rock rippers. Manual loading tools are the conventional ones. Blasting holes are advisable drilled by means of revolving borers suiting to drill large--size holes.

Blasting grade may be different according to the quarrying method. Mere rock blasting should be endeavoured, but even if the quarried material cannot be but blasted, the material should be carefully handled, thus large-size boreholes and deflagrant explosive are imperative. Because of the great variety of perlite deposits, no generally valid blasting technology can be suggested but only directives given for locating the blasting boreholes, pilot tests being needed to determine geometry.

In view of the likely perlite yields, transport will be primarily by trucks. In case of such medium-output mines with changing loading spots, railway transport would be unjustified. Neither are often changing mining spots truly followed by continuous belt conveyance or other continuous transporting system.

Truck transport is advantageous by forwarding the mining product rather gently, at a single reloading, to the preparation plant, namely the bucket travels with the product, thus, the transporting equipment is not exposed to the abrasive effect of perlite and a great flexibility in following the changing loading spots as required is provided for. It is, however, unfavourable by requiring good roads to be constructed.

In locating the mine, power and compressed air supply have to be provided for; if this cannot be obtained from nearly, open-pit operation by exclusive diesel-driven mechanization may be realized.

Also water supply and drainage have to be kept in mind. In case of inconvenient terrain features, a pumping equipment may be needed.

4. PERLITE CRUSHING AND GRADING

To be processed /expanded perlite, foamed glass, etc./ the produced raw perlite need crushing and grading, with a view to produce as little fines dead for processing /grains below 0,3 mm/ as possible. Main technological processes in the heading operation are: pre-crushing, drying, post-crushing, fine-grinding, grading and storage.

Perlite is in general an easily breaking, well crushing mineral. These properties prevent it, however, from being crushed by impact pre-crushers such as gyratory crusher, hammer crusher or desintegrator, likely to produce much of unexpanding dust.

According to theories on the particle distribution of crushed heaps /empiric theory by ROSIN-RAMMLER, theorem by KOLMOGOROV-RÉNYI/, distribution curves are generally of lognormal shape, i.e. the frequency /distribution/ curve plotted on linear scale is skew to the left and its peak is shifted towards the ordinate axis /Fig. 1, a/.

Studies by LÁZÁR /5/ demonstrated these rules to be valid only for a minor group of crushers, such as mills and fine crushers /giratory crucher, hammer, etc./. On the other hand, particle distribution is far from irregular for other crusher types but follows certain rules. Crushing perlite rock is fundamentally bound to produce material of a given grading. To select crushers, rules need to be known.

Tests by Lázár showed crushings by jaw and cone crushers to have Gaussian hence normal particle distribution /Fig.1., b/, while these with rollers is tilted to the right for a low crushing degree, hence corresponds to the reflected image of the lognormal distribution /Fig.1., c/. This distribution law was proven to be a special case of a law of general validity. Accordingly, particle distribution character of the crushed bulk /lognormal, Gaussian, or tilted to the right distribution/ depends on crushing impacts.

This statement is supported by tests on different crushers, of technological importance. In rollers, the rock is crushed once, and in case of a low crushing rate, it is exposed to little crushing effect; passing between the double cylinder, the rock is actually exposed to crushing only along the narrowest opening of the double cylinder. On the contrary, in jaw breakers the particles are exposed to several crushing effects even if crushed once, upon sliding in the crushing jaw towards the orifice, while in hammer breakers, crushing effects number high.

Variation of fomed slag grading crushed in a jaw breaker is seen in Fig.2. based on test results by UJHELYI /6/. Single, double etc. crushing means foamed slag of max. 80 mm size to have been passed once, twice etc. trough the jaw breaker.

For the sake of careful crushing, pre-crushing is done in a jaw breaker as a rule. The pit rock is first dumped on a heavy vibrator partly selecting particles below 100 m size, partly forwarding coarse material into the jaw breaker. Grading of the pre-crushed material can be deprived from its moisture content depending on the mine features but troublesome for grading and expanding by drying at about 150 °C /a higher temperature would strip it from part of its crystal water of impotance for expansion/.

Among plant-size driers, the revolving-drum drier is unsuitable exclusively because of its crushing effect. Shaft driers /Fig.3./ may be recommended where the material settles by gravity, against a counter-current of drying medium /air-diluted flue gas/ by and by aerating the particles.

Heat supply of shaft driers is best provided by oil or gas fuelled heating equipment, applying flue gas from fuel burnt at a high efficiency, automatically diluted with air, as a drying medium.

Where electric power is cheap, an electric IR dryer may be applied but only for drying fines, rather than coarse grains.

After preliminary drying it is advisable to separate particles below 20 mm from the all-in perlite crushings, to reduce dusting losses. Materials drier than 1 vol.% of humidity can be screened. Only particles over 20 mm will be recrushed. Secondary crushers have to be preceded by buffer deposits providing a few hours of reserve to prevent minor pre-crusher breakdowns from disturbing the smooth operation. If the quarried rock contains no excess water /beyond 1 Vo.%/, drying may casually be avoided.

Re-crushing purpose is to refine dried perlite crushings 20 to 100 mm size to max. 20 mm size. Toothed or graticulated rollers are the most convenient, in addition to simplicity, they are advantageous by forming little fines as stated introductorily . The double cylinder has to be mechanically fed, conveniently by a cylinder batcher of variable rpm.

Crushings from the toothed or graticulated roller get in a screening machine where particles below 2 mm size get to final fines sorting while particles over 2 mm get on a smooth casing roller, refining 2 to 20 mm size to 0 to 2 mm fines. The roller is advisably provided with a mounted cylinder grinder, since without re-griding, annular wear due to prime material abrasivity impairs efficiency. Perlite particles over 2 mm emerging from re-crushing are returned to be crushed again while fines below 2 mm are classified into final fractions. Separation in course of crushing is done by a vibrating screen, while the final crushing is fractionated by a vibrating screen or a Mogensen screen /Fig.4./. Also winnower screening may be applied, but revolving cyclones are not advisable partly because of no sharp separation and partly because of excessive wear.

Screening should be developed with flexible method since the market may demand variable particle sizes. As an example let us refer to the perlite mine and mill in Pálháza /Hungary/, in recent years marketing the following sizes to cope with demand:

- 0-0,5 mm; 0,3-1,6 mm; 0,3-2 mm /below 0,3 mm max. 6 pct by weight/ and 0,3-2 mm /below 0,3 mm max. 40 pct by weight/
- 0-0,4 mm; 0-1,2 mm /below 0,3 mm max. 10 %/; 0,8-1,6 mm; 0-2 mm /below 0,3 mm max. 6 pct by weight/
- 0-0,4 mm; 0,4-1,2 mm; 1,2-2 mm /below 0,3 mm max. 15 pct by weight/.

Fractions corresponding to the actual demands are collected in silos of capacities smoothing irregularities resulting from the intermittent operation of crushing and grading equipment and from the equally intermittent material shipment.

The rather abrasive raw material markedly wears out the crushing and grading equipments, hence perlite crushings are to be fed into transporting equipment to minimize machine surfaces exposed to abrasion or to protect these surfaces with anti-wear lining or else.

Efficient dust prevention should be enchanced because of the risk of silicosis due to the aluminium silicate content of perlite. According to the industrial experience, moist-type dedusters of low water demand are the best.

During loading and transporting, the crushed perlite has to be protected from rain.

For a systematic and continous quality control of final product /perlite grinding/, most crushing-screening plants include a laboratory equipped to physical and mechanical testing of the rock or the grinding, also for technology tests /expanability/. Principal laboratory equipments are: laboratory jaw crusher and smooth roller, testing screen set, laboratory winnover screen, laboratory exsiccators, laboratory expanding furnace, implements to test density, chemical composition, bulk density.

5. PERLITE EXPANSION

The primary requirements for expansibility are: the material to be expanded should melt at a relatively low temperature /900-1000 °C/ and part of the water content must be so soundly combined that it only evaporates after the material reached the pyroplastic state. If these two conditions can be controlled according to above requirements, the steam pressure expands the perlite grains. Perlites loose part of their water content only well above the boiling point of water.

By stopping the heating and a relatively quick cooling of the expanded grains, the expanded state can be stabilized.

The role of water is stressed as being most important in the expansion, whereas other volatile materials will be neglected in the following. The water of perlite consists of two parts: the "soundly" combined water is the so called "effectiv" water having a decisive role in the expansion, the "loosely" combined water, however, is harmful for the expansion.

Theoretically, for an expansion multiplied by 30 - presuming that all the water in the perlite is used for the expansion - only about 0,6-0,8 pct. /by weight/water is needed. In reality this is not sufficient because part of the water escapes through pores and fissures of the raw perlite grains without having an active part in the expansion. In addition, on the surface of perlite grains - due to the usual outside heat impact - a local overheating i.e. melting occurs and so water near the surface creats no foaming at all or to a smaller extent than in the interior of the grain. In practice, perlites with a water content less than 1% have a smaller expanding capacity than perlites with higher water contents.

Perlites have an optimum water content which depends on the chemical composition, the macrostructure, the pores, on the method of heating and due to latter on the grain size of the raw perlite. In general the optimum of effective water content is 1-1,5 % for the best known sorts of perlites. Should the water content exceed the optimum, it is advisable to dehydrate the perlite by preheating before expansion but not always since the improved quality obtained by these means is either not in accordance with the surplus expenses or the requirements regarding the finished product do not necessitate it.

To expell water exceeding the optimum, drying devices are used. In practice two solutions came into general use: either before crushing of the raw material or immediately before expansion. Dehydration is carried out usually at a temperature of 250 °C to 500 °C. The proper preheating time and chosen dehydration temperature depends on the grading of the perlite, on the available equipments and the heat treatment method, but fundamentally on the quantity of water present in the perlite and within this, on the quantity of the combined water, further the mode of combination. In Figure 5. characteristic dehydration diagrams are shown.

There is a temperature optimum for perlite expansion. Below this temperature the glass material viscosity and the surface stress remain too high, in consequence the expansion is not satisfactory, on the other hand no melted layer forms on the grain surface, the pores and fissures are not blocked, therefore part of the water can escape without doing any "work". Is the temperature too high, the expanded perlite slumps or becomes baked.

Selection of the expanding temperature depends on the composition of the perlite and especially on its alkali content. An optimum of resulting expansion is obtained at a lower alkali content at a higher temperature, in case of a higher alkali content at a lower temperature. The usual expansion temperature change between 900 and 1100 °C.

Duration of the heat treatment is very important. It also depends on the perlite sorts. There are quickly expanding "live" perlite sorts and others, expanding "with difficulty". Latter must be heated longer. It should be mentioned here that perlite sorts expanding "with difficulty" have less expanding capacity and can be used to produce perlite units of greater density and greater strenght. The "live" perlite has to be heated within 1-3 sec. In Fig.6. a characteristic expansion diagram is shown. As illustrated in the Figure, the length of expansion time depends also on the expansion temperature: at a lower degree of heat the expansion may take longer and viceversa.

The grain size must allow for the interior of the grain to reach also the pyroplastic state during the short time of the heating, however without melting on the surface or agglomeration. In practice this grain size is less than 3 mm, though excellent results can be obtained with gradings of less than 2 mm.

There are different grain sizes within a given fraction /e.g. 1-2 mm/, whereas the heating temperature is given. The total bulk of smaller grains reaches sooner the expansion temperature, the largest grains - later. A good expansion must solve the problem of keeping the small perlite grains for a short time, the large grains for a long time on the expansion temperature.

According to the above, neither expansibility of a perlite raw material can be determined unambigously by theoretical means or chemical-physical tests not the parameters to be used. Tests must always comprise laboratory tests and pilot-plant or large-scale industrial expanding experiments.

At the beginning /about 30 years ago/ the only type of furnace which could assure approximately the necessary parameters for perlite expansion was the rotary kiln, placed at an angle of about 5^{o}-10^{o}. This first rotary kilns functioned on a uniflow basis and direct heating. The raw perlite was fed directly into the flame. The perlite grains were rolling and tumbling in the drums till expanded. At present, relatively few rotary kilns are operating. They are only used to produce aggregate for the building industry and for expansion of perlites hard to expand. According to some authors a rounded off product with more closed pores can be obtained, du · to the rolling movement in the kiln /see Fig.7./.

The vertical furnace with a small angle of slope is not rotating and can be considered as an advanced variant of the rotary kiln. This type was developed in Hungary. Fundamentally it is a tube, lined with refractory ceramic bricks, tilted at an angle of 12^0. This type of furnace functions also based on the uniflow principle. At its higher part the perlite is fed directly into the flame. When expanded the perlite leaves the furnace with the gas fume flow. For heating a specially adjusted, special burner is used. The productivity of a slightly tilted vertical furnace is higher than of the rotary kiln and is suited to produce perlites of lower density with low investment costs and with small specific power consumption. The output of this type is remarkable: 20-25 m^3 expanded perlite per hour. The gas fume flow in the furnace must assure that the expanded perlite grains are swept off by it, however the raw perlite should remain in the flame, i.e. the setting rate of the raw perlite must be higher than the velocity of the fume.

In the two equipments discussed above, the perlite is heated directly by the gas fumes or the ceramic lining. The disadvantage of both is that the expanded perlite and the not-expanded dead material stick on the furnace lining and have to be removed periodically.

The vertical furnace is the type most used and it was developed especially for perlite expansion. It expands the perlite in a vertical cylinder, tapered at the lower end. The raw perlite is charged through one or more openings on the casing of the cylinder above the tapered part.

It is characteristic for these furnaces that the raw perlite enters gravitationally the furnace chamber and falls freely against the fume flow. With the narrowing of the cross section the velocity of the fumes increases in the conically narrowing space according to the law of continuity. The velocity in the narrowest cross-section - this is the highest velocity of the fume - is called "closing velocity". The dropping velocity of the perlite grains slows down in this narrowing zone.

While dropping the expansion of the perlite grains begins their surface increases and density decreases. In consequence the "floating velocity" of the grains is slowing down, first the dropping velocity of the perlite grains becomes zero, then because of further expansion the grains leave the furnace together with the gas fumes in the reverse direction. Floating velocity is the velocity at which the vertically blown grain is floating, i.e. the velocity of the material is zero.

The completely expanded perlite grains leave without slip the expanding furnace practically at a rate equal to the fume velocity. The fume velocity has to be adjusted in a way that the not-expanded perlite grains drop out at the bottom. As smaller perlite grains are carried out by the fume flow even at a minor rate of expansion, care must be taken that no great temperature drop should occur along the furnace.

The burner is installed in the narrowest cross-section at the lower open end of the furnace. In many cases several burners are used. Oil or gas heating is provided. In general the burners are placed to be easily swing-aside. The fume temperature can be controlled by change of the quantity of fuel and air input, Chiefly such burners are applied where the burner head is not built-in into the control device transporting fuel and air input /pumps, ventilator, valves, etc./ and where the produced heat quantity can be infinitely changed between certain limits.

In vertical furnaces two types can be distinguished according the lining used: refractory concrete and heat-resistant steel lined furnace.

Furnaces built of refractory concrete consist of 3 sections /see Fig.8./. The lower part is of a water cooled cone frustum type. The cooling water streams upwards in the casing. The middle part is also of water cooled refractory concrete, here the water flows downwards. Water cooling prevents sticking of the perlite. The top cylindrical part of the furnace is air-cooled. In the bottom part of the furnace 3 low-pressure burners are fitted at an angle of 35°. The cooling air of the upper part supplies the air input and is introduced above the burner at 2 opposite places. Gate valves control the air input.

The raw material is charged into the top section through four feeding funnels, placed near to each other at equal distances. The different perlite fractions /less than 5 mm, 0,5 to 1 mm, 1-2 mm and 2-3 mm/ can be charged through different funnels and the larger size grains through the top funnel. The raw perlite falls freely to the lower conical section, where the grains float till expanded, then are driven upwards and get into the separating system consisting of four cyclons.

In case of the vertical heat-resistant steel lining tube the solution of the usual furnace construction is as follows:

The furnace is double-walled. The inside heat-resistant steel sheet is sorrounded by an exterior normal steel cylinder. The exterior cylinder reduces the heat-loss and develops a controlled cooling possibility of the lining, resp. The cooling air circulates in the space between the two casings. The top part of the heat-resistant steel lining is cylindrical, its lower part tapered. For charging the raw perlite usually two "funnels" are available.

The heat-resistant steel lining prevents sticking of perlite on the furnace wall. Namely, the heat-resistant steel is cooled from the exterior and by this the furnace wall temperature can be kept at 200-300 °C lower than the furnace chamber. To prevent sticking a good flow and a smooth surface of the furnace wall are also important.

A disadvantage of the vertical furnace so far is that perlite streaming out of the furnace is subject to a change of 90° and to collision, resulting in undesirable perlite breaking up. To reduce this effect and to develop plant less high perlite expanding furnaces were set up with a slope more than 35°. The operating principle of these furnaces can still be considered as a floating process.

The raw perlite grains fall or roll in the furnace wards at first, then expansion setting in, their velocity decreases, becomes zero and afterwards is reversed. The lining of the furnace is of heat resistant steel, the arrangement is similar to that in the vertical furnaces.

It is valid for all the perlite expanding equipments that a much better product can be processed of homogenous, strictly graded, narrow raw perlite fractions than of heterogenous, mixed fractions. This prevails gradually with the vertical furnaces. In general the parameters of the furnaces can be changed for expanding succesfully several perlite fractions separately.

The development efforts show two directions: instrumentation and automatization of existing equipments and development of special perlite expanding eqipments. With the measuring and the registration of parameters and their change by remote-control, even the idea computer aided control can be realised.

Recently special perlite expanding equipments are developing but only in laboratory scale, e.g. rotary kiln with vibrating layers, furnaces with moving bottoms /the quick heating tunnels are set up like ceramic furnaces/, horizontal flame-bed formed by numerous gas-burners. For these furnaces homogenous perlite grains of equal size are needed, as every grain stays in the furnace at identical heat conditions, for a length of identical time.

There are two solution for the location of perlite expanding plants: location at the perlite quarry and location at the place of use.

The transport of the raw, crushed perlite is by far more economical than that of the expanded perlite - in the latter case the loadbearing capacity of the vehicles is not fully utilized. Therefore the second solution can be advised.

In general perlite expanding plants can be devided into 3 units:

- reception, storage, handling of the raw perlite
- expansion
- separation, packing.

The raw crushed perlite must be protected from rain as far as possible. Solutions may be manifold and here local features and economical possibilities must be extensively taken into account.

From handling by mechanic shovels and stockage in piles or completely mechanized manipulation by instruments and automatization, many solutions are possible. Means of one of these are /in the sequence of the handling/: covered waggon, unloader, conveyer, storage tanks, feeder, conveyer, storage tank per day.

For the perlite expanding equipment the solutions are much more strict. With tests of the available perlite and the demanded product, the expanding equipment suitable for the given raw material must be determined. The furnace was already discussed previously, here only the units in close connection with the furnace are mentioned.

For feeding raw perlite into furnace usually a cell vibration charger /or a disc charger/ is employed with smooth variation in at least 2-3 times its range.

For dehydration of the raw perlite a drying drum is used. The drying drums have direct oil gas heating with a counter-flow or uniflow solution. The drying drum is placed in a manner that the material gets into the expansion furnace directly. Dust is exhausted from the drier and separated with the usual cyclones.

Cooling of the perlite which leaves the furnace is in close connection with perlite expansion. The cooling agent is mostly cold air. Its quantity and method of introduction must be carefully chosen. If suddenly much air is introduced the expanded grains "blast" i.e. get very much crushed because of the great change in temperature. On the other hand, if not enough cooling air is introduced, the cooling cylinder must also be of a defined heat resistant steel, but the danger still exists that the expanded perlite "slumps", becomes denser. A good result is obtained with gradual, so called "soft" cooling.

The units ranged after the furnace should be placed in a way to avoid as much as possible deviation of direction in the progress of the expanded perlite: the streamy perlite should not collide with wall surfaces. From this point of view the rotary kiln and the fixed cylindrical furnace with a small angle of slope are both unfavourable. In both systems the perlite bumps into a vertical wall at the end of the collecting chamber and the collecting shaft, resp. suffering multiple changes of direction. However the tilted furnace has the advantage that there a minimum of change of direction occurs in the way of the expanded perlite and even the cooling air reduces further the probability of collision of the perlite grains and the wall of the cylinder

The separation and packing equipments are determined by the requirements specified for the finished product. Though these appliances are similar because the perlite is transported by the air flow and consequently separating and classifying devices are also aerotechnical equipments.

To produce perlite packed in sacks for general purposes the separator includes the following units:
- coarse perlite separator
- coarse perlite collector and sackfilling tank
- fine graded perlite separator
- fines collector and sackfilling
- dust separator
- exhaustor
- chimney.

For separation of coarse perlite, chamber and cyclone type separators are in wide-spread use. Advantage of the cyclone separator is that it does not break up the

the perlite as much as the chamber separator, at the same time the perlite is cooled more intensively compared to the other separators.

For separation of the fines, in general a multi-cyclone plant is employed. For dust separation the moist and collecting bag, the fabric /dry/ collectors are the most popular. A great advantage of the dry collectors is that the separated dust can be used and no slurry manipulations requiring much place and labour /setting apparatus, transport, annihilation/ are necessary. Above advantages and development in the material of filter cloths /polypropylene and glass-fibre filter cloths/, had the result that new plants are always provided with collecting bags for fume separators.

The expanded perlite goes from the separators through double air-locks or feeding cells into the collectors and from there over the filling machines into sacks. If the material was filled into plastic /polyethylene/ sacks, it is advisable to put after the coarse separator a further perlite cooling stage. An intensive cooling can be obtained only in a cold air flow. In some cases water cooling of the sackfilling machine might prove sufficient.

Perlite expanding plants can be considered open-air plants, only the furnace control and the end product packing have to be set up in covered places.

Labour demand of these plants is low and power demands also moderate. The most important cost factor is the heating energy.

Figure 9. shows sketch of a perlite expanding plant without the raw material handling appliances.

6. EXPANDED PERLITE IN BUILDING

6.1 Use of perlite in loose condition

The simplest use of expanded perlite for thermal insulation is in form of loose bulk. This is illustrated on a wall construction of hand-size hollow masonry units where superimposed block holes separated by bottom plates are filled with perlite. Each course in place, the perlite may be poured from the bag through a funnel into the holes. Hand-size units being max. 25 cm in height, loosely filled in perlite will little settle afterwards.

According to American data, the original heat transmittance $k_1 = 1{,}37$ W/m^{2}K of a foamed slag concrete wall construction 20 cm thick of hand-size masonry units decreased to $k_2 = 0{,}35$ W/m^{2}K filled with perlite /i.e. the thermal conductivity $\lambda_1 = 0{,}55$ W/mK decreased to $\lambda_2 = 0{,}20$ W/mK/.

A Hungarian example of thermal insulation of industrial building roofs is shown in Fig.10. Joints of the precast roof slabs have been sealed with adhesive plastic sheets. Perlite has been sprinkled with 50-100 liter of water - depending on its bulk density - mixed in a gravity mixer, poured between wooden frames mounted on the roof, compacted with a roller or batten and screeded. The screeded moist perlite surface was superposed by precast foamed slag concrete units and joints have been filled with a lime-cement mortar.

Foamed slag concrete slabs have been designed with joints to form a continuous channel system 2 by 3 cm in the lower surface. The roof structure covered with foamed slag concrete units has at last been coated by a pebbled bitumen felt layer.

This channel system is completed by tinplate vent pipes at the nodes of a mesh 3 by 3 m or 4 by 4 m, as shown in Fig.11. This is aimed partly at permitting drying of the moist perlite through the channel system, and partly, as the vapour entering the perlite through the floor to leave.

This method of application requires the water quantity needed to dampen perlites of different bulk densities and gradings, relationship between compacting degree and insulation density, and the rate of drying through the vent pipes. According to tests made at the Hungarian Institute for Building Science /7/, these characteristics have been recapitulated as follows.

Bulk density and grading of perlites of identical provenance and identically expanded are related according to Fig.12 /8/ thus, bulk density, easier to determine, can be started from. For the sake of simplicity, freshly mixed perlite to water mixture densities are shown in Fig. 13 versus bulk density, for 1 m^3 of perlite mixed with different water quantities and for different compacting pressures. For example, mixing a perlite of 100 kg/m^3 bulk density under a compacting pressure of 0,2 MPa with 50, 100 and 150 litres of water will result in fresh densities of 250, 350 and 440 kg/m^3 respectively. After evaporation of the totel water content, the perlite insulation density will reduce to about 170 kg/m^3 /irrespective of the water dosage/, at an assumed thermal conductivity of 0,05 W/mK.

Accordingly, for a given compacting method, the water dosage is about irrelevant for the density, hence for the thermal properties of the dry insulating layer but significantly affects the drying rate. In the case of roof insulation shown in Figs. 10 and 11 the drying rate of perlite to water mixes compacted by 0,4 MPa pressure is plotted in Fig.14 vs. water content.

Light metal plates /e.g. aluminium/ are made into cavity walls with perlite fill in the cavities for thermal insulation. This system is encountered in the building industry for lightweight structures but it is familiar in the shipbuilding industry.

American booklets recommend perlite for floated floors. The floor slab is covered by 6 to 8 cm of perlite, sprinkled with water and screeded. It receives a coat of bituminous felt superimposed by a cement mortar screed about 4 cm thick. According to Hungarian examinations, perlite floating layer has poor sound-damping characteristics, hence forbidden in the standards.

An ingenuous system of using expanded perlite without binder is the so-called "perlite quilt" developed at the Lightweight Concrete and Insulation Enterprise in Hungary. Primarily it is intended for floor insulation but it can be applied also for insulating attics, dwelling subfloors, sandwich systems, aerated crosswall panels and non-load-bearing plateforms of cold storage houses. Bird's eye view and section of the perlite quilt is seen in Fig.15. In unloaded condition, perlite quilt consists of freely arranged tubes filled with perlite, not contacting each other, while laid on the floor and coated with a cement mortar, the tubes get into contact to form an insulation layer exempt of thermal bridges. It is fitted by spot sticking to the floor, its surface reqires a mortar coating of 3-4 cm thick. Before finishing, it is advisable to compact the adjacent perlite quilts by passing a roller. In Hungary, perlite quilts are made in thickness of 6, 8 and 10 cm, in weights of 6 to 15 kg/m^2 depending on the perlite bulk density, with thermal conductivities of 0,04-0,07 W/mK. It is made in standard commercial sizes of 250 cm length, 50 or 50 cm in width.

Hickmann and Ratcliff /9/ describe uses of perlite in loose bulk form and thermal insulation at subzero temperatures. They report of thermal conductivity coefficients λ = 0,04 and 0,024 W/mK determined for loose perlite of 50 to 80 kg/m^3 bulk density exposed to +20 °C and +15 °C on the warm side, and 0 °C and -190 °C on the cold side, respectively. They state thermal insulation of perlite ~~insulation~~ to much increase upon vaccum treatment. As an axample it may be quoted that perlite of 96 kg/m^3 bulk density exposed to +20 °C on the warm side and -183 °C on the cold side exhibited thermal conductivities λ = 0,023, 0,014 and 0,0022 W/mK at atmospheric pressure, at 1 mm of mercury column /0,0014 at/ and at 0,01 mm of mercury column /0,000014 at/ respectively, while under same temperature conditions, a perlite of 132 kg/m^3 bulk density had a thermal conductivity λ = 0,001 W/mK in the 10^{-4} to 10^{-5} mm of mercury column range.

This effect can be enchanced by mixing about 20 % of aluminium powder to the perlite, for decreasing radiation. Under the same conditions as before, the perlite-aluminium powder mixture had a thermal conductivity

λ = 0,0006 to 0,001 W/mK.

Recently loose perlite has been applied for cryogenic purposes. Storage tanks for deep-cooled gases /ethylene -103°C, methane -161°C et c./ are constructed as shown in Fig.16. The gap between the two casings is filled with loose perlite /in a thickness of about 1 m/. It has two advantages: loose perlite has a thermal insulation capacity competitive to that of plastic foams, and the loose bulk can follow tank deformations. Apertures in the tank lid permit to observe and replace perlite settlement.

6.2 Use of perlite with cement binder

One of the earliest methods of using perlite as a thermal insulating material was in form of perlite concrete cast in-situ or in form of precast units. Relevant observations are also valid for the manufacture of other perlite-based products made with other binders. Let us begin with the effect of various factors on the compressive strength and density of perlite concrete, followed by the technology of perlite concrete, then various application fields will be reviewed.

Compressive strength and density are the two most important characteristic of lightweight concretes in general and in particular of perlite concretes. Namely compressive strength is decisive for other mechanical characteristics /bending strength, elasticity, creep, shrinkage, frost resistance, heat and fire resistance etc./ while primordial physical characteristics such as thermal insulation, vapour absorption, thermal damping, acoustic properties, are strictly related to density. Therefore it is more than justified to scrutinize the effect on these primordial, often contradictory properties. This contradiction consists in attempting to achieve the highest strength possible in view of durability, resistance to stresses, while optimum thermal and impact sound damping properties depend on a possibly low density. Obviously, technology parameters providing for an optimum compromise should be endeavoured. The next chapter is intended as facilitating this problem primarily on the basis of Hungarian test results and industrial achievements /10/.

6.21 Various effects on perlite concrete density and compressive strength

Let us begin by presenting an evaluation method recommended as a directive for testing the essential properties of any lightweight concrete including perlite concrete.

Mixing an aggregate with any binder, for instance perlite aggregate with cement, gypsum, lime, bitumen etc., its density and compressive strength will be determined by the binder content, depending ob the compacting degree. Obviously, making a lightweight concrete mix of a given cement:aggregate: water ratio and casting it into the mould without compacting will result in a very low-density and evidently very low-strength concrete. Placing the same concrete mix applying a gentle compacting e.g. ramming will increase somewhat both the density and the strength. Gradually increasing the compacting rate /e.g. vibrating more and more strongly and for an ever increasing time, or compressing at ever higher forces/ will gradually raise both density and strength. Since the same mixing ratio has been applied throughout, because of growing density, cement obtained in m^3 of compacted concrete will be higher. For a lean initial concrete mix i.e. at a low cement to aggregate ratio by weight, ~~the cement,~~ the cement content will not much vary along the density increase. In a rich concrete mix i.e. containing much cement compared to the aggregate, density increase will be accompanied by an enhanced increase of cement dosage.

Fig.17 shows real examples for these variations in case of concretes made with expanded clay aggregate. Density vs. cement dosage has been plotted in Fig.17/a for different compactions and mix ratios, indicating cement:aggregate:water ratios by weight for the different mixes. For instance a 1:4:0,8 mix moulded without compaction got a density of 1050 kg/m^3, corresponding to a cement dosage of 181 kg/m^3. With increasing compaction the density grows; in our example the maximum compactness was achieved at a density 1850 kg/m^3, for a cement content of 319 kg/m^3.

Compressive strength vs. cement content of the same mixes has been plotted in Fig.17/b with a continuous line. The uncompacted 1:4:0,8 concrete /hence, with a cement content of 181 kg/m^3/ is seen to have a compressive strength of 2 MPa while that of maximum compactness/ /at a cement content of 319 kg/m^3/ amounted to 25 MPa.

These two diagrams permit to construct the relationship of maximum interest for us i.e. complex variation of strength and density vs. cement content, Construction is achieved as follows: for a given density in Fig.17/a cement contents of concretes with different mixing ratios are determined. These data are: for mix ratio 1:6:1,1 a cement content of 148 kg/m^3; for 1:4:0,8 - 207 kg/m^3; for 1:3:0,65 - 257 kg/m^3; for 1:2:0,5 - 343 kg/m^3, respectively. These cement contents are projected on strength curves in Fig.17/b and points connected. The connecting curve has been traced by deshed line in Fig. 17/b.

All densities being constructed, results in the nomogram in Fig.17/b show the cement content needed for the maximum strength possible to cope with the density still melting thermal insulation requirements. Let us have a look now on relationship established from the test method described in Fig.17 for cement-bound perlite concretes.

6.21.1 Effect of perlite bulk density

Hungarian tests have led to the relationship according to Fig. 18 between density and compressive strength of concretes made with max 3 mm expanded perlite, and the perlite bulk density /11/.

In conformity with test results, for increasing perlite concrete dry densities, ever higher perlite bulk densities are needed for an optimum strength. Perlite concretes for merely thermal insulation purposes /300 to 400 kg/m^3 density/ are advisably made of a perlite of bulk density ranging from 80 to 100 kg/m^3 to achieve a compressive strength of max. 2 MPa. For a perlite concrete serving thermal insulation and subaltern structural purposes, at a compressive strength of 4 to 5 MPa and a density of 600 to 700 kg/m^3 a perlite of 130 to 150 kg/m^3 density has to be applied.

It should be remarked that all data in Fig.18 refer to perlite concretes made in ideal conditions.

6.21.2 Effect of cement dosage

Hungarian test results /8/ are described in compliance with principles presented in connection with Fig.17. These data are presented on Figs 19 through 22 indicating both fresh and dry densities of perlite concretes.

The cause of these results perplexing at the first sight is easily understood. Processing e.g. a perlite of 150 kg/m^3 bulk density into a perlite concrete of 500 kg/m^3 dry density by placing the mix without compacting /see Fig.21/ is done by making 1 m^3 of perlite concrete with about 1 m^3 i.e. 150 kg of perlite, hence 500-150 = = 350 kg may be the total weight of cement and hydrate water. As a coarse approximation, cement binds 20 % by weight of water, hence there is about 300 kg/m^3 of cement, the excess being the hydrate water. Uncompacted perlite concrete when hardened has a minimum of strength /max 1 MPa/. Making again a perlite concrete of 500 kg/m^3 dry density, however, at an intense compaction /e.g. pressing/, then as much as 2 m^3 i.e. 300 kg/m^3 of loose perlite can be incorporated in 1 m^3 of concrete. In this case the quantity of cement plus hydrate water may amount to 500 - 300 = 200 kg. Now, the cement content is about 170 kg/m^3 but the concrete became stronger owing to the intense compaction, in spite of the cement content being little more than half of that in the uncompacted concrete. /According to Fig.21 now strength amounts to about 2,5 MPa/.

Remind here that perlite concretes have to be made up with rather much mixing water. According to Hungarian test results, applying for instance a compaction by pressing, mixing water requirement concommitant with the given cement dosage was about 20 % by weight, while the water demand of perlite vs. density proceeds like Fig.23. As a conclusion, perlite concrete composition can be calculated as follows:

In knowledge of the required compressive strength and density, cement dosage needed for the available expanded perlite can be read off Figs 18 through 22. Hydrate water is about 20 % by weight of cement, hence from the knowledge of cement content, the hydrate water quantity can be determined. Cement quantity increased by hydrate water has to be deduced from the density: perlite content making up the difference.

Perlite water demand can be read off Fig. 23. Data have to be checked from trial mixes. The calculation will be illustrated on hand of and example.

A perlite concrete of 500 kg/m^3 dry density and 2 MPa compressive strength is wanted, to be made with an available perlite of 150 kg/m^3 bulk density. Design starts from Fig.21. A cement content of 210 kg/m^3 has to be applied. The corresponding hydrate water content /to be reckoned with as mixing water/ is about 40 litres/m^3. Thus, the perlite content amounts to 500-/21o+40/ = = 250 kg/m^3 that is, 250/150 = 1,67 m^3. According to Fig.23, perlite has a water demand of 145 % by weight, i.e. about 360 litres/m^3, resulting in a mixing ratio:

cement dosage	21o kg/m^3	1,00	parts	per	weight
perlite content	250 "	1,19	"	"	"
mixing water 40+360 =	400 "	1,9	"	"	"

adding up to a mixing density of 860 kg/m^3.

To facilitate design, nomograms can be constructed to present dry to mixing density relationship for perlites of given bulk densities. Fig.24 is an illustration for a nomogram made for a perlite of 100 kg/m^3 bulk density, based on the average water dosage in Fig. 23.

6.21.3 Effect of water content

Water mixed to the concrete mixture has double action: partly, to permit cement hydration, and partly, to improve concrete workability. For ordinary concretes, this double action is separated and becomes contradictory. If only the hydrate water for the cement is added /15-20 % by weight of cement/ the concrete will be poorly workable, of a high air content even when freshly mixed, hence, of low strength. For a water dosage to produce fluid concrete, the shuttering will perfectly be filled out to approach exemptness of air occlusions almost without compacting, but then cement paste will be diluted, at a high w/c ratio, naturally resulting in low strength. Thus, the minimum water dosage providing for a pore-free placing with the given compacting means has to be found, to obtain the possible highest-strength concrete.

It should be mentioned that ordinary concrete aggregates practically absorb no water, hence the entity of mixing water will dilute the cement paste.

On the contrary, porous aggregates are highly absorbent, at a water absorption rate of 15 to 800 % by weight /10 to 50 % by volume/. Thus, only part of the water mixed to the lightweight concrete can be used by the cement, most of it will be absorbed by the aggregate. Therefore, with a special view on lightweight concrete strength, the double action of mixing water does not separate and is not contradictory, as the increase of water dosage gradually improves concrete workability, provides a higher mixing density, hence, a gradually higher strength. Figs 19 through 22 point out the strict correlation existing between perlite concrete mixing density and compressive strength /independent of cement content/. Data of these Figures have been processed independently in Fig.25.

Relationships plotted in conformity with principles in Fig.17 are shown in Fig.26, expressing mixing water dosage as a percentage by weight of perlite. Mixes have been calculated with 20 pct of water by weight of cement. According to the Figure, strength is inaffected by the water dosage, but is solely dependent on density of fresh concrete.

Increase of water dosage in perlite concrete is limited exclusively by the risk of excessively compacting excessively plastic mixes, to a density too high to meet thermal insulation requirements.

6.2.4. Effect of concrete admixtures

Admixtures most familiar for ordinary concretes are plasticizers, setting retarders and air entrainers. Among them, plasticizers are irrelevant in conformity with Chapter 6.21.3 stating mixing water increase to improve strength, while exsiccation tests /see Fig.14/ showed excess water to slow down drying rate but drying is sooner or later complete for any water dosage.

Neither use of a retarder is likely to bring about important changes. In ordinary concretes, retarders have the primary function to keep the workability of concrete for a sufficient time. In perlite concretes, this needs no special admixtures since the water dosage is high enough to protect setting until placing has started.

On the contrary, use of air entrainers may be recommended. In American practice, perlite concretes are invariably admixed with an air entrainer. Brouk stated /12/ air entrainers to act as inhibitor to water penetration into perlite pores, reducing mortar water demand. At the same time, microscopic pores improve mix cohesion and workability, and increase the thermal insulation of the hardened concrete without reducing strength. Air entrainers improve perlite concrete yield, hence part of the perlite - depending on the air entrainer dosage - can be saved. Consequently, a perlite concrete of about 400 kg/m^3 density and 1 MPa strength can be made from 1 m^3 of perlite instead of 1,5 m^3 which is necessary without air entrainers.

Percentage of pores is inversely proportional with the cement dosage /13/; with increasing cement dosage pore volume decreases. The same proportionality seems to prevail between particle size and pore content /14/: the less the particle sizes, the more pores there are. Accordingly, perlite concrete is advantageous both by its low cement demand and small particle size, air entrainment being favourable at a low admixture dosage.

6.21.5 Effect of mixing and compacting

Concrete may be mixed in either a gravity-type or an impeller-type mixer, the more advantageous being that offering the more intensive, the more thorough mixing, at a lesser risk of segregation, grain crumbling, at a shorter mixing time. From the aspect of mixing intensity, impeller-type mixers are better, and so are gravity mixers for saving particles. In agreement to tests made both in Hungary and abroad /11/,/15/ mixer type has no specific effect such as to give preference to one type of both.

Mixing for more than 2 min in impeller type mixers risks overmixing: the mix becomes suddenly plastic, fluid, similarly as observed for cement pastes in shear /colgrout/. This phenomenon can be attributed to perlite crumbling. Compacting perlite concretes has been referred to in item 6.21.2. Perlites being of excessively light weight, compacting by vibration in itself is inefficient /e.g. vibrating poker/. Vibration combined with surface loading may be succesful but the same material properties may be achieved by pressing or rolling.

Compacting method and concrete composition - primarily water dosage - are strictly related; the lower the compactor efficiency, the more water is needed to achieve a given density /e.g. in case of a surface loading of 0,02 MPa, the water demand is about 40 % higher than for a surface loading of 0,5 MPa/. Accordingly, the exact composition of perlite concretes can only be determined in knowledge of site conditions /compactor, mixer/, hence on the site, based on the given technology process.

6.21.6 Curing effect

Perlite concrete has to be made at a high water dosage and drying is a slow process because of the high water retention of perlite. Thus, curing needs no wetting, just during the first one or two days the surface must be prevented from excessive drying, Thus, the perlite concretes, either prefabricated or cast in-situ, have to be covered by a plastic sheet or other impermeable layer for at most 48 hours. Thereafter the concrete has to be left drying out, protected from rain.

Hardening of precast perlite concrete may be accelerated by heat curing. In connection with the heat curing of concretes with porous aggregates, tests by Nurse /16/, Ujhelyi /17/, Reinsdorf /18/ and Buday /19/ may be mentioned.

Informative data obtained by Buday in perlite concrete tests are shown in Figs 27 and 28. Fig.27 shows the relation between 1-day relative strength /steam cured to air cured strength ratio at 1 day/ and the isothermal curing time, for perlite concretes with different water dosage. Fig.28 shows relationship between 1-day relative strength and density at failure for perlite concretes isothermally cured for 6, 8 and 12 hours.

Results have led the conclusion that - as against gravel concretes - perlite concretes with higher water contents are better curing. For the sake of an optimum curing Buday suggests to cure perlite concretes made with a due mixing water dosage in hot dry air in the first period of curing, then in the second curing period in a non-saturated steam chamber /at 70 to 90 per cent relative humidity/.

5.22 Design of perlite concrete composition

With a view to factors expounded in item 5.21, making a perlite concrete of adequate grade is primarily dependent on the agreement between the concrete composition /perlite bulk density, cement dosage, perlite quantity and water dosage/ and the compacting implement, that is, a mixing ratio has to be chosen, likely to permit or even demand the most intensive compaction of the fresh concrete, for the given placing conditions.

As an introduction it has to be pointed out that any specification or prescription for concrete making cannot be but informative, namely variable plant conditions, complex requirements and not perfectly uniform basic materials prevent specification of a final concrete composition. Thus, before any concreting work, it is indispensable to make minor trial concreting and control specimens. Obtained results will permit modification of informative values in specifications, and determination of concrete compositions to meet requirements. Stress is laid on the respect of the specified density, to be absolutely checked.

Concrete composition can be expressed by either the weight /kg per cu.m/ of binder, aggregate and water contained in 1 cu.m of compacted freshly mixed concrete, or by the proportion by weight /maybe by volume/ of the components. The former is termed the concrete composition, the latter the mixing ratio.

Hungarian construction and design specifications /20/ recommend compositions compiled in Tables 1 and 2 for making perlite concretes. Table 1 is a compilation of little compacted perlite concrete compositions as a function of perlite bulk density and concrete density, while Table 2 contains the same values for intensive compaction.

Remind that values in Tables 1 and 2 are only informative, to facilitate selection of the mixing ratio for trial mixes. After trial mixing and trial concreting, the actual fresh density of the concrete has to be determined, that may lead to a modification of the mixing ratio. For a density lower than specified, water dosage may be increased, in the opposite case, a higher perlite dosage may be applied.

6.23 Making cement-bound perlite concrete

Perlite may be shipped to the site or plant in bags or in bulk. Before using, the perlite bulk density has to be checked. The mixing ratio determined by trial mixing may be kept until a deviation not more than ±10 % is observed between the average perlite bulk density and that applied in the trial mix. In case of a higher deviation, another trial mixing is needed to determine the perlite concrete composition.

Cement has to be dosed by weight, both perlite and water may be added either by volume or by weight. Mixing is normally done in an impeller-type mixer because of the resulting perfect homogeneity, and in spite of crushing the perlite particles.

[illegible] ly a gravity mixer is available, this one will be op[illegible]ed with horizontal axis. To make full use of the drum capacity, the input opening should be covered. It is advisable to introduce cement and water first and to add perlite to the mixed laitance. Perlite is rather dusting, a dust mask is needed to protect mixer operator from silicosis.

Perlite concrete is less sensitive to transport than ordinary concrete because of its lower drying rate. Nevertheless it is advisably placed as soon as possible after mixing. If longer time /e.g. 2 h/ has to be reckoned with between mixing and placing, then the water dosage has to be adjusted to maintain the specified after transport. Water excess is not over 5 to 8 per cent as a rule.

A high-grade perlite concrete is preconditioned by appropriate placing, that is, pouring into a shuttering, a mould or on a surface and compacting. Concrete composition has to safeguard fresh density after vigorous compacting by means of the available compactor at a maximum difference of +10 %. Compacting may be either by a manual or mechanical rammer, a compacting roller, a platform vibrator or a plate vibrator, a vibropress by pressing of 0,1-2 MPa or a press. No poker vibrator can be applied. Compacting by pressing is especially favourable from technology aspect for precast perlite concrete units /productivity, tolerance/.

In course of manufacture, fresh density of perlite concretes has to be systematically checked. Checking is rather simple in case of precast units by sampling at random and weighing. Also in-situ cast perlite concrete is easy to sample by taking a sample of specified volume, to be weighed for determining the specific density.

After placing, perlite concretes have to be protected for a few days both to rain and to drying out. Relative humidity in a closed space has to be kept at 90 to 95 per cent for max. two days, while outdoors an impervious layer /e.g. plastic sheet/ should cover the concrete. Thereafter, concrete drying out has to be forwarded.

6.24 Perlite concrete properties

Density and compressive strength are the two most important properties of perlite concrete; relevant data have been compiled in Tables 1 and 2.

Shrinkage of perlite concrete is significantly higher than that of ordinary concrete. Some test results obtained at the Hungarian Institute for Building Science /11/ have been compiled in Table 3. Accordingly, the higher the perlite bulk density, or the more vigorously the perlite concrete has been compacted, the less the shrinkage. In spite of its marked shrinkage, perlite concrete is not liable to cracking, because of its high elasticity, enabling it to support important deformations without cracking. American results have been compiled in Table 4.

Because of its high porosity, perlite concrete is not frost resistant, i.e., water saturated perlite concrete exposed to several freezing-thawing cycles, its surface becomes crumbly. Similarly, its high porosity is accompanied by a water absorption of 60 to 70 per cent by volume: the lower its density, the higher the water absorption.

Building physical properties are the most important characteristics of perlite concrete. Relevant data have been compiled in Table 5 corresponding to the Hungarian Specification /21/. Variation of the thermal conductivity coefficient of perlite concretes stored in spaces at different relative humidities are shown in Fig.29 based on Hungarian tests.

Water vapour absorption and desorption are values of utmost importance of thermal insulations. Data of the quoted tests /22/ have been plotted in Figs 30 and 31, referring to vigorously compacted perlite concretes.

6.25 Building uses of perlite concretes

Density and compressive strength of perlite concretes may vary in a wide range depending on the bulk density of the applied perlite, on the compaction degree and other conditions, recommending it for a multitude of applications. As an information, from published data it can be concluded that a perlite concrete exclusively for thermal insulating purposes may only be advantageous with a thermal conductivity of at most 0,12 W/mK. For a poorer thermal insulation /λ in the 0,12 to 0,3 W/mK range/ it can be used for combined structural and thermal insulation, namely for strengths ranging from 15 to 2 MPa to self--supporting structures and for 3,5 MPa and over, even for wall structures supporting floors.

Upon further increasing the perlite concrete strength, its density will regularly grown, at a certain, but not excessive loss of thermal insulation /e.g. thermal conductivity of a perlite concrete of 1000kg/m^3, 3 MPa compressive strength is not higher than about 0,34 W/mK.

Building industrial uses found in the world literature comprise:

Thermal insulation casing for pipelines. According to Soviet data /23/, temperatures indicated in Table 6 have been recorded on the pipeline surface and on the insulation surface. Accordingly, temperature recorded on the outer surface of perlite concrete and perlite mortar insulation 11 cm thick coating a pipeline of 592 °C inner temperature was 66 °C in operating conditions.

Perlite concrete precast units are applied for thermal insulation of reinforced concrete floor structures, as illustrated in Fig.32. Tightly fitting perlite concrete units are arranged on the floor shuttering, then reinforcement is placed, and the structure is concreted with normal concrete, using precast perlite concrete units as permanent shuttering. Ordinary and perlite concrete exhibit adequate adhesion.

Similar principles are underlaying the prefabrication of floor and wall structures with perlite concrete insulation core. A Hungarian example is shown in Fig.33 with cross-section and joints of precast wall and floor slabs.

A wide-range use - perhaps in the greatest quantity - is that for thermal insulation of the roof structure of industrial halls or of the top floor of living houses with perlite concrete. This is normally cast in-situ or monolithical, the floor may be steeply sloping, mildly sloping or level. Both precast units or monolithic concrete may be applied for insulation. In any-case, a due number of ventilation ducts of sufficient cross-section are needed to maintain continuous aeration of the perlite concrete, or to ensure drying out in case of an eventual soaking /or of mixing water in monolithic concrete/. A typical example of monolithic roof insulation - laid over roof shell units - is seen in Fig.34. Drying ducts have to be developed both longitudinally and transversally in the roof structure: for a perlite concrete thickness of 7 cm, a mesh of 30 cm by cm of ventilation ducts is needed, and the ducts are to be connected to ventilation shafts applied in the nodes of an about 6 sq.m mesh. One outstanding element of perlite concrete roof insulation is the ventilation and drying duct system, which when omitted or incorrectly applied induces invariably the failure of the perlite concrete insulation /24/. Namely, thermal insulation of the soaked perlite concrete is significantly poorer than of the dry one, besides, sunshine may cause a vapour pressure on the concrete surface likely to blow the waterproofing layer and to detach it from the perlite concrete surface.

Glued waterproofing layer cannot be applied but on perfectly sound, dust-free surfaces. Although a perlite concrete of good workmanship suits as waterproofing support even at a 300 kg/m^3 density, but a faultless conctruction presupposes a long practice, therefore in general, perlite concretes of 400 kg/m^3 density and below are coated by cement mortar about 3 cm thick as supporting layer for the waterproofing.

The design shown in Fig.33 is encountered in American practice. Perlite concrete insulation 10 cm thick is applied on a corrugated metal sheet supported in turn on a steel truss, with a perlite concrete suspended ceiling on Rabitz-mesh.

Soft, elastic materials are superior for sound-damping then are rigid materials, fundamental for the acoustic properties of perlite concrete insulations in buildings. According to a publication by the Societa Italiana della Perlite, sounddamping by loose perlite layers 6,4; 7,5 and 8 mm thick and by perlite concrete layers of about 500 kg/m^3 density, 13, 15 and 16 mm thick equal that by air gaps 50, 100 and 150 mm, respectively.

According to a paper in Perlite Torch No.2, Vol.1., sound-damping of 40,3 dB of a partition wall composed of perlite mortar applied on a metal sheet and U and plain laths, of a specific weight of 50 kg/m^2 about equalled that of a partition wall 10,2 cm thick, made of hollow bricks with sand and gypsum plastoring, of 170 kg/sq.m specific weight.

These properties suggest perlite for acoustic uses. Noise level reflected from the walls hence arising in the room may be reduced by sound absorbers. A far-reaching elimination of sound reflection is especially important in extended rooms /theaters, concert halls/ where sound reverberation may be heared separately from the primary sound. To this aim precast perlite concrete dadding plates may be applied, doubling as decorative units.

Thermal insulating and structural perlite concretes of 3,5 MPa and over may be processed into partition wall slabs, partition wall units, roof units, external wall units with or without frame, of various sizes.

Compressive strengths of 3,5 MPa and over require either perlites of high bulk density, or efficient compacting work /see Fig.11/. For a perlite bulk density of e.g. 150 kg/m^3, then 1,65 m^3 of perlite is needed for 1 m^3 concrete of 4 MPa compressive strength, while 1,3 m^3 of perlite of 200 kg/m^3 bulk density grants the same strength. Cement bound partition wall plates applied initially by the Hungarian building industry /25/ have later been abandoned for gypsum as binder /see item 6.3/.

Exigencies of the conventional building method /brick or hand-size masonry unit/ are met by partition wall plates of max. 40 by 40 by 8 cm, at a maximum weight of perlite concrete units of 8 kg a piece. For assembly--type building systems with large-size wall structures /e.g. slabs of 3,0 by 0,3 by 1,2 m/, also partition walls are to be made of slabs of perlite concrete, in max. 300 by 120 by 8 cm sizes weighting max. 200 kg.

Prefabricated metal /e.g. aluminium/ framed perlite concrete panels are suitable for temporary buildings that can be assembled, dismantled and assembled again /site buildings, temporary stores, sheds, etc./. This type of unit is outlined in Fig.36. Also large-size wall slabs have been made of perlite concrete for storeyed living houses, single-storey family houses, weekend houses and garages. These wall slabs are partly self-supporting, without reinforcement, with a middle hole for lifting as shown in Fig.37. A two-layered wall unit applied in the

USSR, with an outer layer of gravel concrete, and an inner layer about 5 cm thick of perlite concrete of about 500 kg/m^3 density, is shown in Fig.38 /28/. Besides perlite sand 0 to 5 mm particle size, also perlite granules 5-20 mm particle size, of about 350 kg/m^3 bulk density are made in the USSR. Mix of perlite sand and granules is made into single-layer wall slabs of max. 15 MPa strength concrete, on the other hand, perlite sand of a bulk density of 150 kg/m^3 or over is added to other lightweight aggregates /e.g. expanded clay/ as a substitute for natural sand.

6.3 Perlite with gypsum binder

Gypsum is an indispensable binder of conventional finishing work and becomes ever more extended in the production of up-to-date lightweight building materials. Namely, the quick setting of gypsum permits fast re-using cycles of moulds at a high economy, it is easy to place, yields smooth surfaces and the products are true to size.

Advent of gypsum-bound perlite was simultaneous with that of cement-bound perlite. Just as the cement-bound perlite, the gypsum-bound one is qualified by strength and density. Gypsum-bound perlite will be treated along the same lines as the cement-bound one.

Some gypsum perlite compositions suggested in publications will be tabulated. Table 7 is a compilation of gypsum perlite compositions applied in the USSR. Compositions applied in American practice ar recapitulated in Table 8. In Table 9 compositions suggested for Hungarian perlites have been compiled.

Essential characteristics of gypsum perlite /i.e. compressive strength and density/ are very similar to the cement-perlite. Bending strength is about 30 % of its compressive strength, i.e. a gypsum perlite of about 2 MPa compressive strength has a bending strength of about 0,6 MPa. Relationships for the modulus of elasticity have been plotted in Fig.39 based on Australian data /15/.

Gypsum is known to swell soon after hardening, to a to a max. at 1 day of age, then begins to shrink, to return to original placing volume when dried. The same process is encountered for gypsum perlites.

Gypsum perlite has outstanding refractory and fireproof characteristics. Steel structures coated by 2,5 cm of gypsum perlite resist fire during 1 hour. Remind, however, the increased importance of architectural design of the fireproofing layer or structure for the fire resistance. Protecting the steel structure to fire by applying a gypsum perlite suspended ceiling, rather than a plastering, leaving an appropriate air gap between ceiling and structure may result in a floor that keeps its fire resistance during 4 hours of fire. Besides this the major fields of use of gypsum-bound perlite are: ready-mixed perlite plaster for thermal insulation or fireproofing, suspended ceiling, precast thermal insulating claddings and partition walls.

A method under Hungarian patent for prefabricating hollow partition wall slabs results in units shown in Fig. 40. These partition wall slabs ~~results in units shown~~ are of room height and 60 to 80 mm thick. If applied in a moist room /kitchen, bathroom, etc./ its side facing the humidity has to be coated with a sealing layer, the other side aerated. Slab marerial has a compressive strength of 5 MPa, a sound reduction of 28 to 30 dB and a limiting fire resistance of 1 hour. Its surface is perfectly smooth, after jointing it can be directly painted or wallpapered. Besides, it is workable: can be chiselled, sawn, drilled.

6.4 Perlite's using with other binders

Other binders used to perlites are: bitumen, lime, water-glass, ceramic, magnesia-cement, aluminium phosphate and synthetic materials.

The bitumen binder is used for decreasing the water absorption of perlite. The bitumen must be heated before its using, to the perlite can be mixed only hot bitumen. The warmer the bitumen the better will be every important properties of the product./24/

We have to mention that the too hot bitumen in compacted bitumen-perlite can cause spontaneous ignition, therefore the bitumen can heated only till its softening point +120 °C /e.g. a bitumen with softening point of 80°C can be heated only till 200°C/.

Besides bitumen is used also coal-tar pitch to prefabricated bitumen-perlite products. According to the Hungarian experiences using coal-tar pitch increases the compressive strength and decreases the water absorption. But heating of mixed binder /bitumen+coal-tar pitch/ claims greater care than in the case of bitumen only.

Bitumen bound perlite can be manufactured both in situ and by prefabrication. Bitumen heating equipments must assure the exact temperature of the bitumen. Overheated bitumen is susceptible to spontaneous inflammation. The bitumen-perlite cannot be placed immediately after mixing; a cooling storage place must be provided for, between the mixer and the compacting device. The temperature of the mix is 150-160 °C if a usual quality bitumen /melting point 80-90 °C/ is used with the bitumen-perlite mix at 200-210 °C. For compacting however only a bitumen--perlite mix of a temperature less than 100°C is suitable /advisably 80-90 °C/.

The mix may be compacted by pressing or rolling. For prefabricated products usually a press is used, the press load changes from 0,4 to 1,4 MPa in function of the bulk density, the mixing rate and the desired density. To compacting in-situ bitumen-perlite usually a roller is applied. The casing of the metal roller must be continually cooled while operating, otherwise the bitumen adheres to the metal surface. The pressing plates of the press have to be cooled in the same way. For the cooling water is used.

For the amount and the rate of water absorption data are given in Fig.41. Water absorption rates of bitumen--perlite products different density are plotted against the bulk density of the used perlite. This reveals that water absorption of elements stored for 8 hours in water does not exceed 10 Vol. % and only a very lightweight perlite product processed to a high density unit is above 20 Vol. % /proportion of bitumen:perlite 1:1,1 - 1:1,3/.

Thermal conductivity factor changes in function of the density are plotted in Fig.42. As design value the upper limit graph should be taken into consideration.

This material is used first of all for roof insulation. Its initial water absorption is slow, therefore it gets hardly soaked by a long lasting rain. It may be used for roofs both with minor or great inclination. Its colour is dark therefore the temperature of the insulation might rise to 70-80°C in consequence of long lasting sunshine. This does not deteriorate the bitumen-perlite cover, however it becomes soft and cannot be tread on. A reflecting water-repellent graveled coating, eliminates this set-back.

For perlite-mortar either slaked lime sludge /both of lump quick lime and crushed quick lime/ or hydrated lime may be used. To improve mortar strength - similarly as with normal rendering mortar - beside lime also cement can be mixed to the perlite. Most important in a green rendering mortar is its workability as it determined the bond the density and strength after hardening. From this point of view lime sludge is better than hydrated lime.

Bond between the plaster and the surface depends on the mixing water quantity. For a highly hygroscopic surface a thinner mortar is necessary. The surface must be prepared before plastering: first of all it has to be cleaned of dust and other stains, if too smooth, it has to be stippled, then sprinkled with water or a thin layer of diluted mortar mix is dashed on the surface. To improve plasticity, density and yield some air-entrainers may be added to the perlite mortar.

The composition of lime-bound perlite mortar the Hungarian Code proposes data to be found in Table 10. Perlite plaster can be dashed or spread with the masons usual tools, it is easy to finish and can also be applied with mechanic tools.

The special use of lime-bound perlite is described in a Swiss patent /28/. The dust-like finely graded raw perlite /expedient if below 60 µm/ is kneaded with a small amount of water while intensively mixed with slaked lime. By this, part of the SiO_2 content of the perlite glass can be actived. The perlite dust - lime mix may be used as binder: diluted with water it can be mixed with expanded perlite and the slightly moist mix is pressed into forms. The raw units are autoclaved assuring intensive hydrated calcium formation subsequently they are cured in dry warm air. According to data a thermal insulating and heat resistant product is obtained with a density of 140-210 kg/m^3, a thermal conductivity factor of 0,06-0,07 W/mK, heat resistant up to 950 °C, and a compressive strength of about max. 0,5 MPa. This procedure - taking into account also the technical characteristics of the product - is not a cheap method; there was no information available about its circulation and use the building industry.

Water-glass is a binding and glueing colloid solution, the aqueous solution of either potassium cilicate /K_2SiO_3/ or sodium silicate. The hardening goes on as a result of the precipitation of amorphous silicon due to drying and carbondioxyds. To accelerate hardening, the water-glass is heated and as catalyst sodium silicon tetrafuoride /Na_2SiF_6/ is added.

Properties of perlite concrete prepared with water--glass are influenced by the bulk density and grading of perlite as well as by the binder content, similarly as described in chapter 6.21. Processing methods resemble those of cement bound products /mixing, compacting/, however, the final strength is obtained by drying at a temperature of 160-180 °C. Drying time: some hours, in function of the water-glass quality.

The thermal resistance of this product /at least +800°C/ destines it for thermal insulation, chiefly for industrial equipments, district heating pipelines, and other heating pipes. Water-glass perlites may be manufactured for thermal insulation of buildings, for wall cladding purposes, for suspended ceilings and roof-insulation as well.

Shells and segments of water-glass perlite, produced by the Hungarian perlite industry have a density of 250-400 kg/m^3, the thermal conductivity factor is 0,07-0,12 W/mK, flexural strength 0,2-0,5 MPa, compressive strength 0,4-1,2 MPa.

The weight of refractory ceramicis can be much reduced by addition of perlite, yielding a product with a density of 300-700 kg/m^3. Actually these are not burnt clay products made lighter with perlite, but perlite products with a binder of ceramic origin. They are chiefly used for thermal insulating or refractory elements.

As binder mainly clay with an illite content, bentonite and marl are used. The clay must be dried, subsequently it should be passed a roller mill, a desintegrator and a separating machine. The crushed material and the perlite should be dry-mixed. On the mix proportion gives information the Fig.43. The important properties of Hungarian BIOPORIT is shown in Table 11.

Ceramic-bound perlite can practically be used anywhere, but it is most economical where its high thermal- and refractory properties are utilized /as thermal insulating lining in chimneys or a heat-resistant pipe casing for district heating pipelines of high temperature/. For such purposes ceramic bound products are also manufactured in the USA, in Canada and the Soviet Union /29/ /30/. According to the USA patent specifications the products resist even a temperature of +1650 °C.

Magnesium oxyde is a product obtained of magnesite mineral /$MgCO_3$/, burnt at a temperature of about 900°C then finely ground. It was first applied by Sorel, therefore it is also known as Sorel-cement. Magnesium oxyde with water sets and hardens very slowly, therefore it is generally mixed with magnesium chloride /$MgCl_2$/, magnesium sulphate or solutions of other salts /e.g. $CaCl_2$/. The highest strength is obtained by magnesium oxyde with magnesium chloride; though magnesium sulphate has the advantage of yielding a hardly hygroscopic magnesia-cement.

For industrial uses binders of magnesium are mostly mixed with organic fillers /wood chippings, sawdust/. It is sensible to replace them by perlite, because perlite being an anorganic material is fungus-proof and mould--resistant. Magnesite floors prepared with perlite - similarly to magnesite floors made with sawdust - must not be cured with water, the mix not being waterproof, a dry atmosphere is requested while hardening.

Magnesia-cement-perlite concrete can be well compacted and well screeded. Instead of magnesia-cement also dolomite cement might be used, in which beside magnesium oxyde also carbonate is present, as an inert filler. Because of the inert filler dolomite cement is of poorer quality, this must be accounted for establishing the mix proportions.

Aluminium phosphate is a technical alum earth with a specific surface of 15000 cm^2/g, ground to powder /grain size max. 20 µm/, which is attacked with 60 weight pct of phosphoric acid. Used as binder its heat and fire resistance are well known; therefore perlite concrete, exposed to high temperature are produced with aluminium phosphate.

According to litterary data /31/ perlite concretes prepared with a quantity of binder, depending on the strength to be obtained, can be used up to a temperature of max. 1200 °C. Both strength and fire resistance depend on the density of the perlite-concrete. If the density /measured on dehydrated aluminium-phosphate-perlite concrete/ is max. 600 kg/m^3, the temperature maximum reaches 1000 °C, of the density has a max. of 1000 kg/m^3, the temperature maximum may reach 1200 °C. In general perlite may be exposed for longer period to a temperature at which it was expanded, however aluminium phosphate developed a protecting cover around the perlite grains, therefore the material resists also higher temperatures.

Depending on the quantity of the binder and the intensity of compacting, the material with a density of 600-1000 kg/m^3 has a compressive strength of 1-15 MPa. They are used for furnace linings, fire-resistant cladding of steel bearing structures, etc.

The polymerisation procedure for increasing strength of the cement bound perlite was applied in the USA. Very detailed experiments were carried out in the National Laboratory, Brookhaven /32/. For the laboratory tests cement-bound perlite concretes of very different quality were prepared and these were saturated by different methods with monomers and subsequently polymerised. The density of perlite concretes /in dry condition/ was between 360 and 490 kg/m^3, after being saturated with a monomer and polymerized, it increased to 1100-1200 kg/m^3. At the beginning compressive strength of the original perlite concrete was 1,2-1,3 MPa, after polymerisation it reached 34-56 MPa. Other technical properties /frost--resistance, resistance to corrosion, etc./ of high grade polymer perlite-concrete were also favourable. As a result of the tests, experimental break-away lamp posts were manufactured.

The flexural strength of precast units can be increased - both for better handling and higher durability - by using fibrous materials /such as slag wool, basalt wool, glass fibre, etc./. The fibre reinforced perlite concretes can be used basically with any binder, however in practice they are used mainly to manufacture water--glass and cement-bound perlite products. The most delicate phase of the technology is the even distribution /mixing/ of the fibrous material. The usual mixers are not suitable for this purpose, therefore, the so-called beating drum known in the asbestos-cement production, is used. The machine results in further crushing the perlite grains, however it ensures the completely homogenous distribution of the fibrous material.

The Johns-Manville /USA/ corporation offers the licence and machinery for "Fesco Board". According to the prospectuses, the continuous production based on the modified binder - the object of the licence - with shredded fibres /earlier organic, now anorganic/ and perlite, offer among other varieties of the product also fireproof and hydrophobic types. They can be manufactured in storey-high boards with different widths and thicknesses.

For acoustic purposes the American firm CELOTEX has a new product, the so-called glass-ceramic slab. Accordir : to a few available data, it is manufactured as follows: t! : perlite is poured into heat-resistant steel moulds, go :s through an arc-light furnace where the grain surfaces fuse and agglutinate. Size of the product changes from 60 to 120 cm, it is flame- and fume-proof, and has a fair resistance against chemicals. The prospectus states that its acoustic properties are excellent.

7. USE OF PERLITE FOR COARSE AGGREGATE AND FOAMED GLASS

Of crushed and graded perlite other lightweight products, chiefly for the building industry, can be produced by some special ways, besides the usual expanding technology, discussed in Chapter 5. The manufacture of foamed glass and the so-called granulated foamed perlite /further on: PHG/ are discussed below /Hungarian patents/. Based on experiences with numerous perlite samples, almost all proved suitable for producing foamed glass and PHG. The more suitable the perlite for manufacture of foamed glass and PHG, the more vitrified phases it contains, i.e. the smaller the proportion of crystalline phases.

Sketch of the technology for the production of a decorative volcanic foam is as follows:

- fine crushing perlite rock /less than 100 m/
- mixing perlite dust with chemicals
- drying the moist dust mixture /at 200-250 °C/
- crushing the dried mixture /to less than 3 mm/
- fine grinding the pre-crushed mixture /to less than 100 m/
- filling the fine dust mixture into the expanding form /shutter/
- foaming the dust mixture in the furnace /at 800-860 °C/
- stripping foamed glass plates
- cutting and grinding the foamed-glass plates to exact sizes
- application of the decorative layer /by dry or wet means/
- curing /stoving/ burning-in of the decorative layer /depending on the decorative material, at a temperature of 600-700 °C/

- classifying, packing.

Production technology sketch of granulated foamed perlit /PHG/ is as follows:

- fine crushing the perlite rock to max. 3 mm size, then grinding it to max. 100 μm
- mixing the perlite dust with chemicals
- granulating of the moist mixture
- drying the granulated material /below a temperature of 300 °C/
- classifying of the dry granulated material on a vibrating screen
- expansion of the granulated material in a gas or oil heated rotary kiln at a temperature of 800-900 °C
- grading of the expanded grains by means of a vibrating screen, a drum screen or a swinging chute
- storage and packing of the granulated foamed perlite

The chief technical features of the decorative volcanic foam can be summed as follows:

Its density /average/ is of 350 kg/m^3, which can be diminished till 250 kg/m^3 or increased to 450 kg/m^3. Water absorption: 0-2 pct by Vol., but it can be increased importantly /e.g. to suit acoustic purposes/ even to 50-70 pct by Vol. The foam with a water absorption of 0-2 pct by Vol. is frost-resistant.

Compressive strength comes to 3-8 MPa depending on density; flexural strength: 1,8-3,5 MPa. Thermal conductivity at a temperature of 20 °C, measured on sheets of 20x20x3 cm is 0,078-0,125 W/mK. Average coefficient of thermal expansion till 500 °C comes to 35.10^{-7} m/m°C.

Temperature limit of use is max. 300 °C, beginning of melting: 550-600 °C.

The units are made in Hungary in sizes up to 40x40x5 cm in plate forms. The material can be well cut, sawn and ground.

Chief possibilities of use for volcanic foam and decorative volcanic foam are: thermal insulation layer on loadbearing floors, in precast sandwich slabs, thermal insulating wall claddings for dwelling-houses and for industry halls /e.g. for cold-storage plants/, thermal insulating decorative face and interior cladding and artistic elements.

The main technical properties of the granulated perlite foam are as follows:

Density: 100-250 kg/m^3

Grain size: 4-35 mm

Porous structure: uniform, mostly closed

ASTM self-strength /for grain size 10-30 mm/ at a density of 130 kg/m^3: 1,4-1,6 MPa, while at a density of 190 kg/m^3: 2,4-2,6 MPa.

Water absorption: 3-5 pct by Vol., but it can be increased to 50-60 pct by Vol.

According to DIN 4226/3/b the PHG is frost resistant.

The granulated foamed perlite can be used in the following fields:

In the concrete technology as lightweight aggregate for concretes with densities of 400-1200 kg/m^3 and with strengths of 1,5-10 MPa. It can be associated with synthetic foamed products, e.g. a product consisting of 70 pct PHG and 30 pct foamed polyurethane /by weight/ has the properties as follows:

Density: 175 kg/m^3, thermal conductivity: 0,055 W/mK /at a temperature of 20 °C; compressive strength: 1 MPa; flame resistant.

8. USE OF PERLITE FOR DIFFERENT PURPOSES

Expanded perlite was found useful not only in the building industry, but also in other fields. Among others, it is applied in agriculture, in the food industry, the chemical industry, in packing techniques, in metallurgy, even for environmental protection purposes.

8.1 Perlite in agriculture

Cultivated plants develop only in a soil able to provide them with water, air and nutritive matter simultaneously. About agricultural application of perlite the first world literature information was issued in publications of the Perlite Institute /USA, New-York/. Here the experiences with perlite of the Texas floricultures were discussed and it was proposed to use it for ornamental plants and tobacco seedlings. Perlite preparations /e.g. trade mark Perl-Lome/ were applied purely instead of soil, together with high dosages of nutritive maters.

Since the beginning of the sixties perlite is also applied in Europe for horticultural purposes, thus at the experimental plantation of the Swiss Eidgenössische Versuchsanstalt für Obst-, Wein- und Gartenbau, observations were made with strawberry, vegetables and floricultural plants.

Perlite is most suitable for vegetative propagation, for plants cultivated from cuttings, for cultivation and root taking of wine cuttings. In Germany, Holland and Sweden it is also in use to transport young seedlings. In Bulgaria, Czechoslovakia, Yugoslavia it is used as basic material in mould mixes. In the Soviet Union as artificial medium, e.g. in the Siberian power stations experiments were also carried out to use expanded perlite as basic material for hot-house cultivation.

In Hungary the first experiments concerned use of perlite on arable land for monocotyledonous, dicotyledonous and hybrid sorts of plants, also for pot plants, for root taking purposes in nurseries and cultivation of vegetables /33/. The results of laboratory and large-scale tests proved, among others for tobacco, that if perlite is planed 15-20 cm into the soil layer of the tobacco seedling beds /on a seedling cultivation area of 25 m^2, 140-200 liters perlite/, the sprouting occurs 4-5 days earlier, there are less weeds, root taking is more active, plants get not damaged when uprooted and after bedded out greater quantities of seedlings develop - 20-28 % - compared to those cultivated in soil without perlite addition.

Field tests showed that the complex effect of perlite is most utilized when applied during the autumn fitting of land. The depth of the ploughed layer is at this time the greatest and the soil utilizes winter rain best in this way. Perlite used in any cultivation branch yields better results when its grain sizes are larger /2-3 mm diameter/. This perlite type should be used for cultivation of ornamental plants /e.g. carnation, geranium, germination of chrysanthenum, for root taking, replanting/, horticulture /soil-amelioration, for parks and terrain correction/, mixed with nutritive matters /starter sulphur/ for meadows and pastures, for sowing different grasses, beet-root, rice, etc. As an admixture to soil disinfectants or extirpators perlite is a satisfactory carrier medium.

8.2 Perlite for reducing evaporation

Agriculture needs water and a considerable part of it comes from standing waters. On account of evaporation water losses increase significantly all over the world, therefore numerous solutions were developed to stop it. In the United States until recently long chain acrylic monomolecular film-like layers were applied, however they are easily blown away by the wind. To replace them experiments with perlite were begun /34/.

Perlite was first hydrophobized by silicon /see Chapter 8.3/. Perlite grain size 0,1-1,2 mm; bulk density 100 kg/m^3. The perlite can be dumped from sacks directly on the water surface at one place and the slightest, breeze suffices to spread it, the covering whole surface. After a while, small part of the perlite may sink in the water or the wind might carry it away, so about 0,2-0,25 liter/m^3/week perlite is wanted. Is the perlite highly hydrophobic, the value of perlite consumption can be reduced to 0,07 liter/m^3/week.

According to test results, the water temperature in summer is 2-2,5 °C less than for the uncovered water immediately under the surface and 3-5 °C lower at a depth of about 1,0 m. Not much perlite is carried away by the wind. As a wind effect the perlite cover might pile up on the opposite side to the wind direction /the covered surface may be reduced to 50-60 %/, after falling of the wind, it forms again an unbroken layer.

With a perlite covered water surface a long-term water economy was achieved in average of about 20% according to summer tests, the cost of the economized water was

0,38 dollar/m^3 water.

In the USA tests it was also investigated whether perlite was not damaging to fish because the water was shut off from sunshine - in principle by a reflecting layer. It was found that in cooler weather length and weight of some kinds of fish /e.g. trout/ did not change, however surviving ratio was better in perlite covered water. With other fish and in warmer weather /e.g. tylapia/ the perlite cover is harmful. The cause may probably traced back to reduced nutritive matter content, because development of algae diminished.

8.3 Hydrophobized perlite

In some fields use of perlite has the disadvantage of its high water absorption /30-70 % by Vol./. To reduce it hydrophobizing methods had been developed.

To obtain a permanent hydrophobic effect, it is necessary that the polar groups of the dehydrating liquid form chemical combinations, assuring with the ions or atoms of the hydrophil solid the outer orientation of the non-polar carbo-hydrate roots. If such an orientation of the molecules was secured, the carbo-hydrate roots prevent the connection between the water molecules and the components of the solid. In case of porous material, hydrophobization occurs only if there is no water pressure.

To hydrophobize perlite homologous carboxylic acids or their salts, bitumenous solutions, water solutions of aluminium or calcium soaps or different forms of organic silicon compunds might be considered. Most efficient are bitumenous materials and organic silicon compounds.

Perlite with a water absorption of 50-60 % by Vol. in the original condition, reaches at a maximum 3-10 % by Vol. if well hydrophobized.

Hydrophob perlite is able to bind oil on its surface therefore oil adsorption is an other important feature. Coarse graded perlite /grain size larger than 0,2 mm/ has an oil adsorption of 4-7 ml/g.

Hydrophob perlite acquired a special role in cleaning oil polluted waters. As perlite grains hardly absorb any water poured on the water they float for a long time without sinking. But as the grains adsorb oil on their surface, the oil pollution adheres to the perlite. The oily perlite is gathered by simple methods and lifted from the water together with the oil, bound to their surface.

8.4 Perlite for filter aid material

In the food industry /sugar-, beer-, canning industries, and viticulture/ as well as in other industries /chemical, petrol-chemical and pharmaceutical industries /anorganic powders with a large specific surface /e.g. diatomaceous earth/ are used as filters. For this purpose a specially prepared expanded perlite proved suitable; often less material is needed and filtering becomes quicker, as with traditional filter materials. Tests carried out at different places proved /35/ that 0,6-0,7 kg right quality filter perlite suffices for 1 m^2 filter area, in case of sugar 1-1,2 m^3/m^2h filter performance could be achieved with the same filter effect as for traditional filter materials.

In the food-, chemical- and pharmaceutical industries only perlites of special quality and composition can be used as filter aid materials. Filter perlite of less strictly specified properties - therefore much cheaper - are most helpful for environmental protection /36/.

Environmental pollution has an increasing tendency, pollution of the environment endangers even the population. To prevent ruining the rivers, sewage must be purified and treated, also waste water filters have to be applied for clarification of manure slops in agriculture. For such purposes industrial by-products were already in use with more or less success, fly-ash, or breeze, etc. However they have so unsteady properties that the result obtained is also uncertain.

The perlite powder /generally of less than 0,3 mm grading/, handled as worthless material remaining after raw perlite crushing, is suitable to make an expanded perlite of a relatively small grain size but a large specific surface. According to pilot-plant tests with this kind of filter perlite, carried out in Hungary, oily sewage in a refinery could be clarified to a less than 1 mg/liter oil content without any special investment /the original oil content was 30-80 mg/liter/. Taking into account above data for a plant, letting out 10000 m^3 sewage per day, a perlite consumption of 12-15000 m^3 per annum has to be considered.

8.5 Perlite in metallurgy

Perlite has two main utilization in metallurgy:

- as ingot mould insulating sheet
- as metallurgical backing sand.

Metallurgical works are investigated since decades how the steel could be kept warm for as long as possible after casting. The slag inclusions drift upwards in the cast steel and settle on top of it. If the cast steel is cooling to quickly, the whole ingot might become unserviceable. Even if it was kept warm, 6-8 cm have to be cut off on the upper part, in many cases still more, because of the slag inclusions. If the height of the cast steel could be increased by some centimeters, this would be a great economic benefit.

The exothermal insulations applied in metallurgy so far, with carbon as basic material and containing iron--aluminium thermite, were very expensive, instead perlite can be well utilized. The mix is: coarse perlite ~~can be well~~ 92 %; water-glass mixed refractory material /composed of: 90% clay, 8% water-glass, 2% water/ volume. If perlite contains much fines, thermal insulation and gas penetration decrease.

Prefabricated thermal insulating shells are formed of the mix, their inner side, in contact with the steel, is coated with a quickly drying material, made of water--glass and siliceous flour, to diminish friability and gas penetration. The insulating shells must be dried for 2-5 hours at a temperature of 150-200 °C.

The mould profiles can be made of the same mix also by vibrator-peesses. Water absorption is small, thermal insulation good, no gas formation occurs, therefore the steel after getting into the mould remains quiet. Of course care must be taken that no CO_2 gas generating agent should penetrate into the mix /e.g. the refractoiry material should not contain magnesits or chalk /otherwise the steel begins to boil in the mould/.

8.6 Other uses of perlite

Expanded perlite as a chemically and biologically neutral, dry, light-weight, sift and elastic material, is suitable for any packing where the transported ware has to be protected against damage due to impact or shock, i.e. it has to be bedded in an elastic material. It can substitute saw-dust, chippings, etc. Compared to them it has the advantage to be biologically neutral, does not rot, mould and is warm resistant. It can be utilized to transport plants /onions, bulbs, etc/, to store vegetables and potatoes /in latter case its thermal insulating capacity is a further advantage/.

In engineering it is used for anti-vibration mounting. According to a Hungarian patent, a synthetic resin dispersion is mixed with perlite, a plastifier and an anticorrosive. When drying, the mass does not shrink. Vibration of large-size sheets for waggons and buses are damped by spreading the mass between the two cover sheets. It has also a sound-proofing effect.

Fine grained perlite is also utilized in powdered soap and detergents as rubbing and cleaning agent, making use of its faint abrasion effect. Because of its water absorption capacity reduces clotting and is easy to disperse.

Used as a filler in asphalts, perlite raises the melting point and reduces brittleness.

Expanded perlite has a great specific surface, is insoluble in water and in organic solvents therefore suitable as pigment vehicle in paint and varnish production /37/.

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Table 1.: Some compositions of slightly compacted perlite concrete

Bulk density of perlite in kg/m³	Mixing ratio by weight /cement:perlite:water/	Density of concrete in kg/m³: fresh	Density of concrete in kg/m³: after drying	Density of concrete in kg/m³: with stabilized water	Concrete composition: cement in kg/m³	Concrete composition: perlite in kg/m³	Concrete composition: perlite in l/m³	Concrete composition: water in l/m³	28 days compressive strength in MPa
60	1:0,56:1,60	540	300	350	170	100	1600	270	0,1 - 0,2
	1:0,46:1,35	680	400	240	240	110	1850	330	0,3- 0,6
	1:0,36:1.10	780	500	570	315	115	1900	350	0,8 - 1,2
	1:0,30:0,95	900	600	680	400	120	2000	380	1,5 - 2,0
100	1:0,93:2,06	560	300	350	140	130	1300	280	0,1 - 0,3
	1:0,80:1,80	720	400	460	200	160	1600	360	0,4 - 0,8
	1:0,65:1,50	850	500	570	270	175	1750	405	1.0 - 1,6
	1:0,52:1,24	965	600	680	350	180	1800	435	2,0 - 2,5
150	1:1,80:2,90	570	300	350	100	180	1200	290	0,2 - 0,4
	1:1,47:2,40	730	400	460	150	220	1450	360	0,8 - 1,2
	1:0,98:1,70	845	500	570	230	225	1550	390	1,8 - 2,2
	1:0,80:1,40	960	600	680	300	240	1600	420	2,5 - 3,5
200	1:1,47:2,00	670	400	460	150	220	1100	300	1,3 - 1,7
	1:1,25:1,70	790	500	570	200	250	1250	340	2,5 - 3,5
	1:0,93:1,32	910	600	680	280	260	1300	370	3,5 - 4,5
	1:0,75:1,11	1030	700	790	360	270	1350	400	5,0 - 5,2

Table 2.: Some compositions of strongly compacted

Bulk density of perlite in kg/m^3	Mixing ratio by weight /cement:perlite:water/	Density of concrete in kg/m^3 fresh	after drying	with stabilized water
60	1:0,90:2,45	625	300	350
	1:0,65:1,83	760	400	460
	1:0,50:1,46	810	500	570
	1:0,40:1,20	915	600	680
100	1:1,40:3,00	625	300	350
	1:1,10:2,40	780	400	460
	1:0,85:1,90	920	500	570
	1:0,65:1,50	1020	600	680
150	1:3,00:4,60	600	300	350
	1:1,60:2,60	725	400	460
	1:1,15:1,90	850	500	570
	1:0,86:1,50	970	600	680
200	1:2,10:2,70	690	400	460
	1:1,30:1,75	810	500	570
	1:1,00:1,40	920	600	680
	1:0,80:1,16	1040	700	790

perlite concrete

Concrete composition				28 days compressive strength
cement in kg/m³	perlite in kg/m³	perlite in l/m³	water in l/m³	in MPa
145	129	2150	350	0,1 - 0,3
215	141	2350	400	0,5 - 0,9
295	147	2450	425	1,0 - 1,6
375	150	2500	450	2,0 - 2,5
115	162	1620	345	0,2 - 0,4
175	191	1910	415	0,8 - 1,2
245	201	2070	465	1,4 - 2,0
325	211	2110	485	3,0 - 3,5
70	210	1400	320	0,4 - 0,6
140	225	1550	360	1,2 - 1,7
210	240	1600	400	2,3 - 2,7
290	250	1650	430	3,8 - 4,2
120	250	1250	320	2,3 - 2,7
200	260	1300	350	3,8 - 4,2
270	270	1350	380	4,8 - 5,2
350	280	1400	410	6,6 - 7,4

Table 3.: Shrinkage of the perlite concrete /11/

Bulk density of perlite in kg/m³	Concrete composition in kg/m³			Density of concrete in kg/m³		Shrinkage of concrete in mm/m after				
	cement	perlite	water	fresh concrete	dried concrete	7 days	28 days	60 days	90 days	120 days
80	100	176	404	680	300	0,24	0,98	1,45	1,88	2,11
	160	104	226	490	300	0,36	1,25	1,82	2,56	2,85
	170	184	406	670	400	0,21	0,87	1,31	1,69	1,97
	240	112	298	650	400	0,31	1,19	1,68	2,38	2,59
	250	190	470	910	500	0,18	0,75	1,12	1,37	1,59
	310	120	330	760	500	0,26	1,02	1,44	1,79	2,02
200	70	310	330	710	400	0,17	0,71	1,04	1,16	1,31
	150	220	250	620	400	0,25	0,97	1,32	1,56	1,87
	130	340	370	840	500	0,13	0,54	0,78	0,89	1,07
	220	230	280	730	500	0,18	0,81	1,11	1,32	1,49
	190	370	410	970	600	0,08	0,26	0,44	0,62	0,73
	300	240	300	840	600	0,15	0,62	0,85	0,92	0,99

Table 4.: American data of thermal insulating perlite concrete

Density of dried concrete in kg/m3	Compressive strength in MPa	Cement content in kg/m^3	Water content in kg/m^3	Air entrainer in $1/m^3$	Thermal conductivity in W/mK	Thermal expansion in $10^{-6}/^oC$	Tensile strength in MPa	Young modulus in MPa
575	3,1	375	302	4,2	0,111	11,0	0,53	1740
488	1,9	302	295	4,2	0,092	9,9	0,35	1110
432	1,3	251	268	4,2	0,084	8,6	0,28	840
384	0,9	215	268	4,2	0,074	8,1	0,21	660
352	0,7	189	268	4,2	0,073	7,7	0,14	490

Table 5.: Thermal insulation characteristics of perlite concretes

Density of dried concrete in kg/m^3	Specific heat in kJ/kgK	Thermal conductivity in W/mK	Temperature conductivity in m^2/s	Specific heat absorption in $J/m^2s^{0,5}K$	Heat absorption in W/m^2K	Water vapour diffusivity in kg/msPa
300	1,128	0,116	$0,000342.10^{-3}$	196	1,663	$0,050.10^{-9}$
400	1,128	0,139	$0,000326.10^{-3}$	252	2,150	$0,046.10^{-9}$
500	1,128	0,163	$0,000309.10^{-3}$	309	2,625	$0,042.10^{-9}$
600	1,128	0,198	$0,000292.10^{-3}$	364	3,100	$0,040.10^{-9}$

Table 6.: Temperatures measured in perlite concrete insulation

Pipeline	Units of the insulating construction	Layer thickness in mm	Temperature in °C inside the pipe	under the insulation	outside the insulation	average	Thermal conductivity of insulation in W/mK
Pipeline's diameter 44 mm	1st layer: casing from perlite concrete	50	592	550	253	402	0,127
	2nd layer: segment from perlite concrete	50	592	253	89	171	0,113
	3rd layer: perlite mortar	10	592	89	66	77	-
Pipeline's diameter 133 mm	1st layer: casing from perlite concrete	50	485	450	280	365	0,113
	2nd layer: segment from perlite concrete	50	485	280	169	225	0,112
	3rd layer: segment from perlite concrete	50	485	169	64	117	0,090
	4th layer: perlite mortar	10	485	64	39	52	-

Table 7.: Composition of perlite plasters on basis of Soviet data

Key to the signs:

1.: Mixing ratio by volume /plaster:perlite/
2.: Mixing ratio by weight /plaster:perlite:water/
3.: Fresh density of plaster in kg/m^3
4.: Dry density of plaster, in kg/m^3
5.: Gypsum content of plaster in kg/m^3
6.: Perlite content of plaster in kg/m^3
7.: Water content of plaster in kg/m^3
8.: Compressive strength of plaster in 0,5 hour /MPa/
9.: Compressive strength of plaster in 28 days /MPa/

1.	2.	3.	4.	5.	6.	7.	8.	9.
1:2	1:0,2:0,96	1010	650	[illegible]	100	445	1,5	3,0
1:3	1:0,3:1,20	915	550	366	110	440	0,6	1,5
1:4	1:0,7:1,57	890	480	300	120	470	0,4	1,0
1:6	1:0,6:2,14	830	400	222	133	475	0,3	0,6

Table 8.: Composition and properties of thermal insulating perlite plasters /The Perlite Torch, B.2. No.3./

Key to the signs:

1. Bulk density of the expanded perlite in kg/m^3
2. Perlite content of the plaster in kg/m^3
3. Gypsum cpntent of the plaster in kg/m^3
4. Density of the dry plaster in kg/m^3
5. Thermal conductivity in W/mK

1.	2.	3.	4.	5.
100	130	550	750	0,126
100	130	420	620	0,115
100	130	300	500	0,106
60	85	600	750	0,126
60	85	470	620	0,115
60	85	350	500	0,106

Table 9.: Composition and properties of perlite plasters on basis of Hungarian investigations

Key to the signs:

1.: Bulk density of the expanded perlite in kg/m³
2.: Density of the dry perlite plaster in kg/m³
3.: Gypsum content of plaster in kg/m³
4.: Perlite content of plaster in kg/m³
5.: Water content of plaster in kg/m³
6.: Retarder content of plaster in kg/m³
7.: Compressive strength in 28 days /MPa/
8.: Thermal conductivity in W/mK

1.	2.	3.	4.	5.	6.	7.	8.
130	400	150	200	370	1,5	0,8	0,105
		150	200	370	-	1,0	0,105
	500	230	210	380	2,3	1,5	0,116
		230	210	380	-	1,8	0,116
	600	300	230	420	3,0	2,2	0,140
		300	230	420	-	2,8	0,140
	700	360	250	470	3,6	3,5	0,163
		360	250	470	-	4,5	0,163
60	400	230	120	290	2,3	1,0	0,105
		230	120	290	-	1,2	0,105
	500	300	140	340	3,0	1,7	0,116
		300	140	340	-	2,0	0,116
	600	350	130	430	3,5	2,4	0,140
		350	180	430	-	3,0	0,140

Table 10.: Composition of perlite mortars

Key to the signs:

1.: Bulk density of the expanded perlite in kg/m³
2.: Lime-paste in 1 m³ of perlite /litre/
3.: Lime hydrate in 1 m³ of perlite /kg/
4.: Cement content /mark: ISO 250/ in 1 m³ of perlite /kg/
5.: Water content in 1 m³ of perlite /litre/
6. Density of the fresh mortar in kg/m³
7. Density of the dry mortar in kg/m³

1.	2.	3.	4.	5.	6.	7.
60	200	-	-	300-350	600-650	320
100	250	-	-	250-300	550-600	320
60	-	120	-	300-350	500-550	320
100	-	150	-	250-300	450-500	320
100	330	-	100	240-280	600-650	420
100	-	200	100	240-300	540-580	420

Table 11.: The most important features of Hungarian "RIOPORIT"

Feature	Unit of measure	Type a	Type b	Type c
Fire resistance	°C	900	900	1350
Density	kg/m^3	290	290	700
Compressive strength	MPa	min. 1,2	min.1,2	min.3,0
Thermal conductivity	W/mK	0,07	0,07	0,21
Pore volume	% by Vol.	81-89	81-98	72
Softening point at 0,025 MPa	°C	910-950	910-950	1710-1780

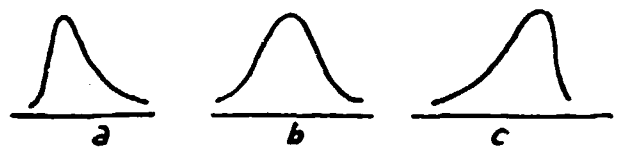


Fig 1. : Grain distribution by different crushing

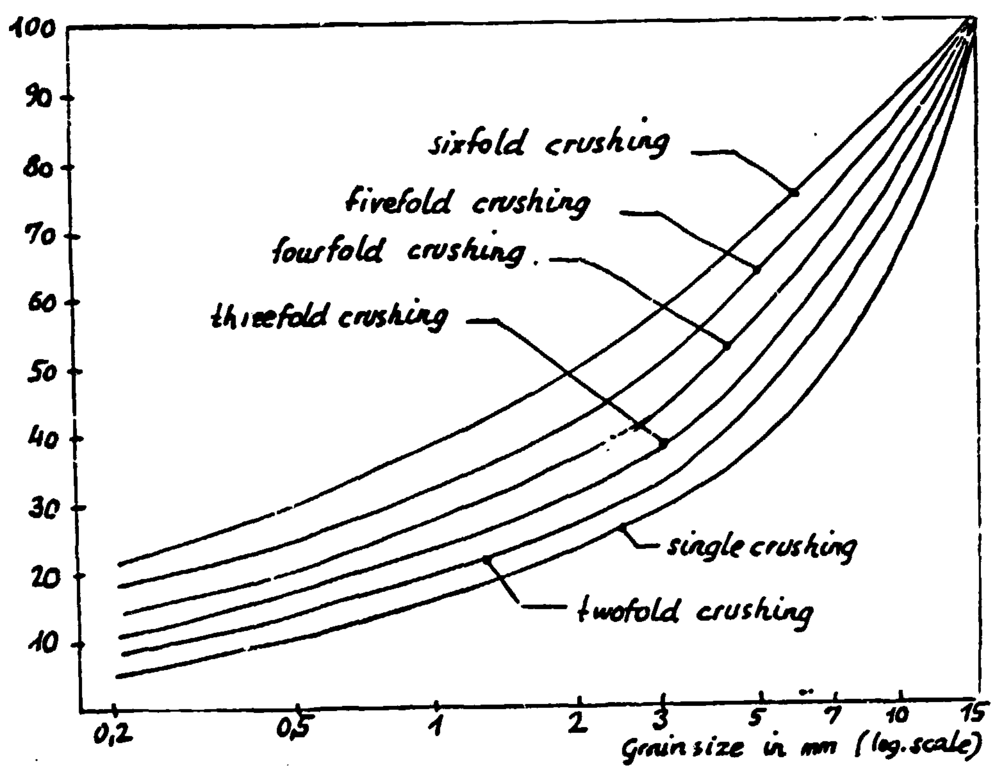


Fig. 2. : Grading of rhyolite tuff crushed in jaw-crusher

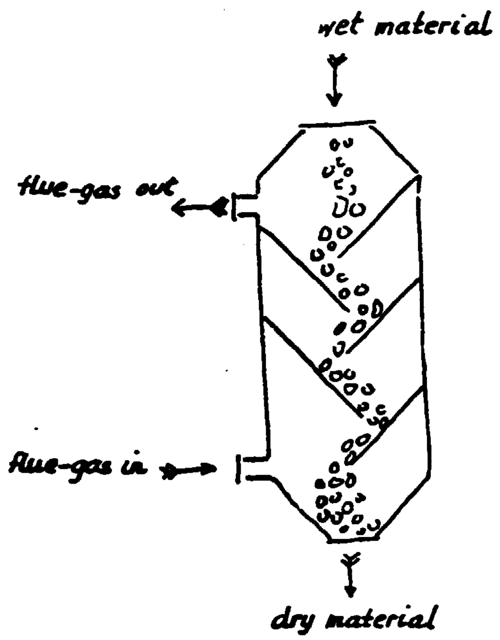


Fig. 3. Scheme of drying kiln

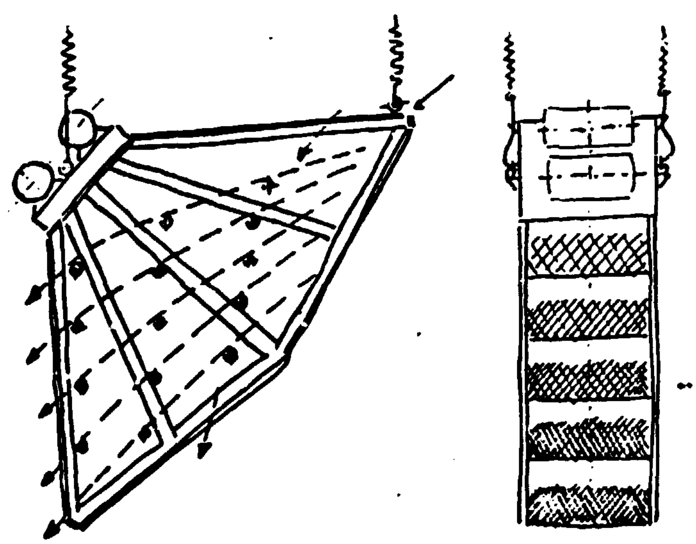


Fig. 4. Scheme of Mogensen-screener

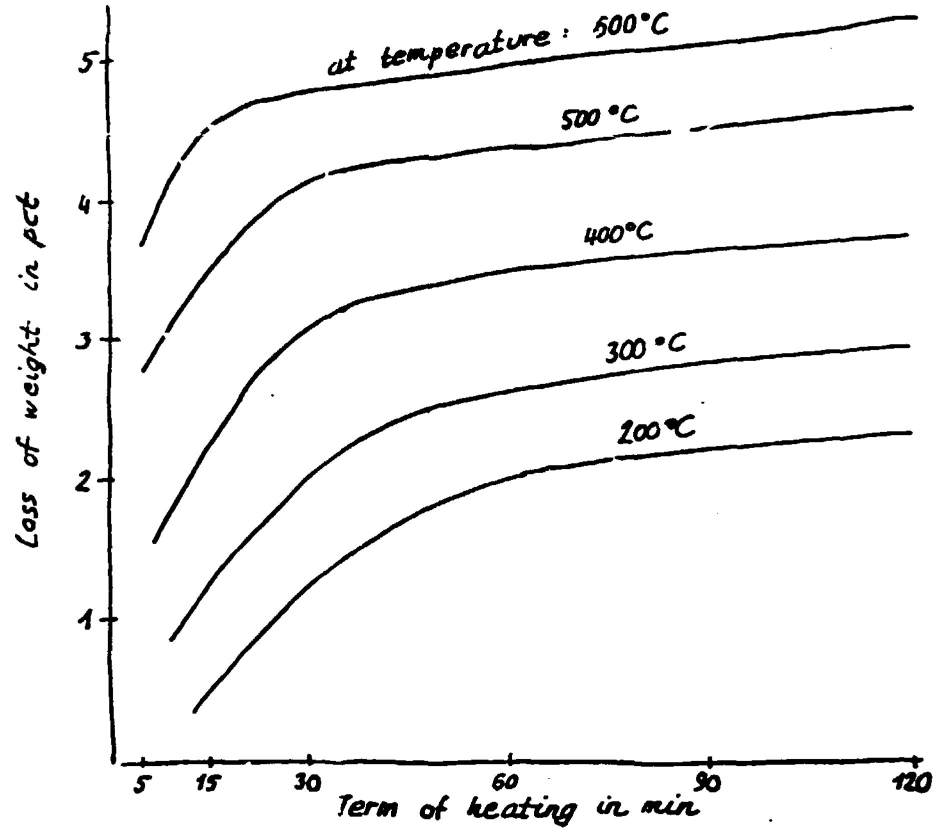


Fig. 5. Characteristic curve of dehydration

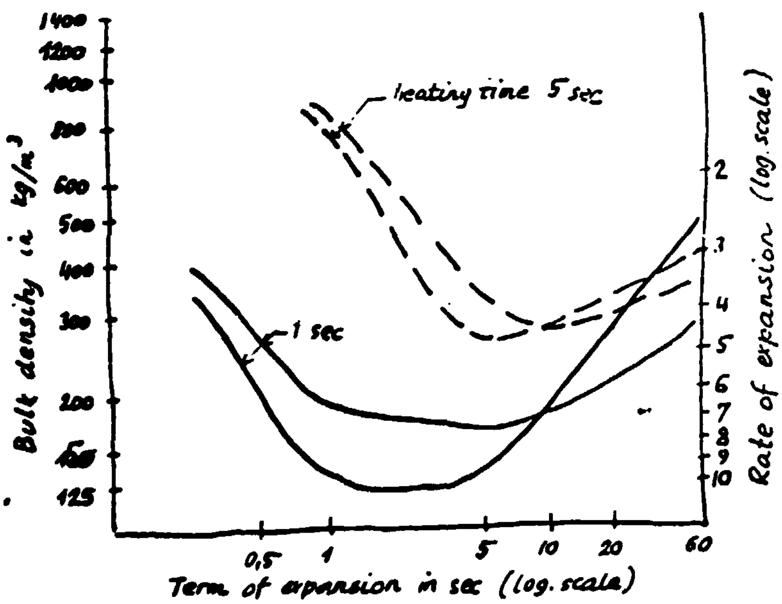


Fig. 6. Expansion rate of Hungarian perlite at different temperatures depending on term of heating and expanding

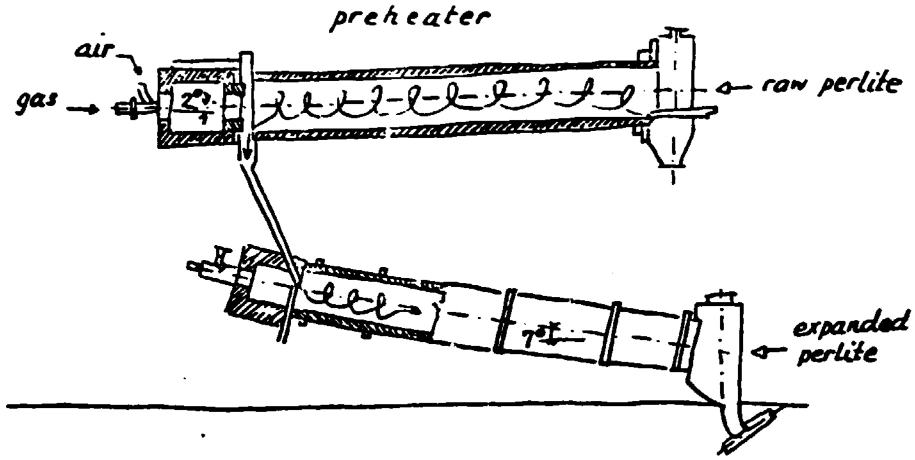


Fig. 7. Rotary kiln for expanding perlite with preheater

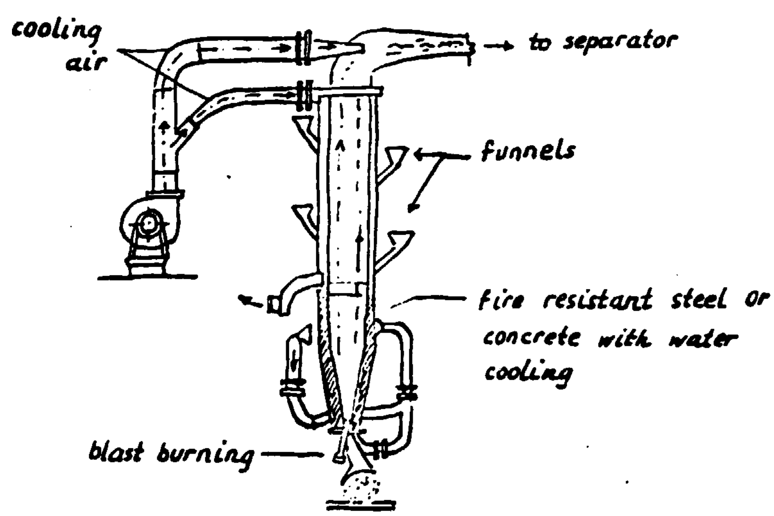
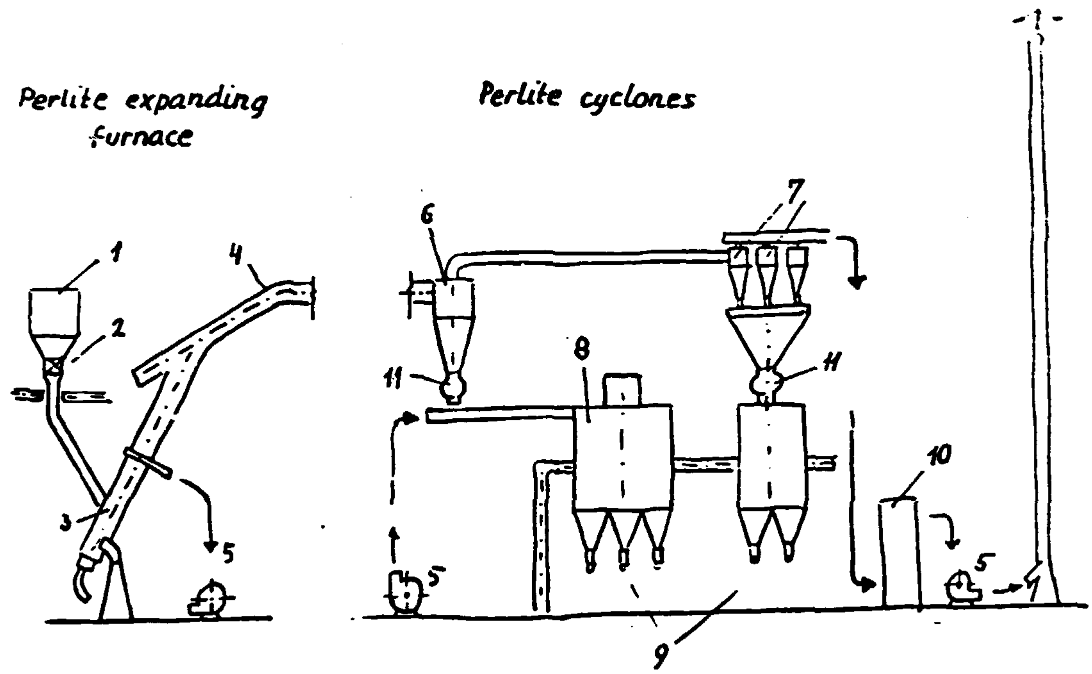


Fig. 8. Fluidization furnace



1. Daily container
2. Feeder of raw perlite
3. Furnace
4. Cooling pipe
5. Ventilator
6. Rough cyclone
7. Fine cyclones
8. Container of perlite
9. Sacking stub
10. Dust separator
11. Cell feeder

Fig. 9. Scheme of perlite expanding and separating workshop

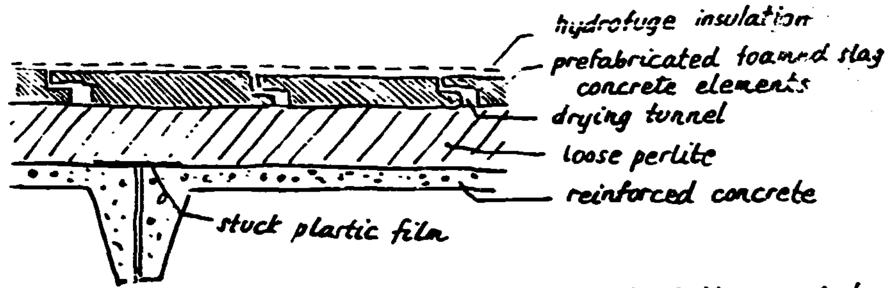


Fig. 10 : Roof insulation with loose perlite

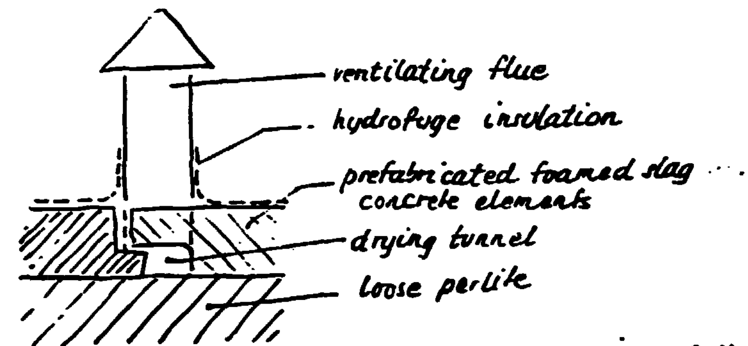


Fig. 11 : Ventilation of the loose perlite

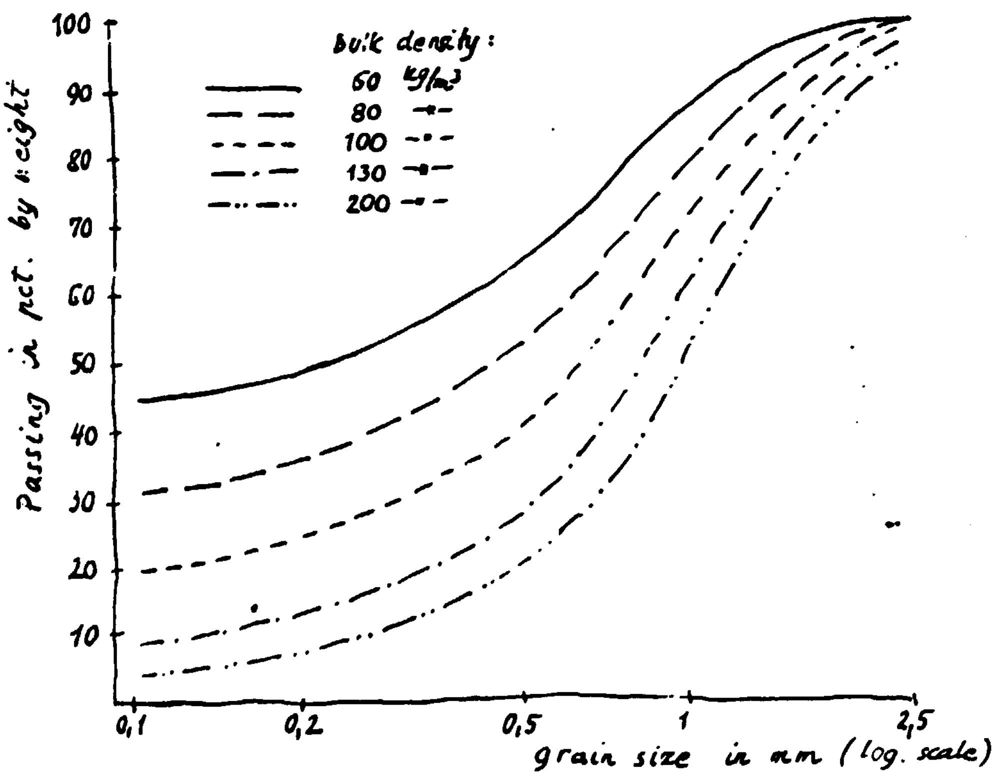


Fig. 12 : Relationship between the bulk density and the grading of perlite

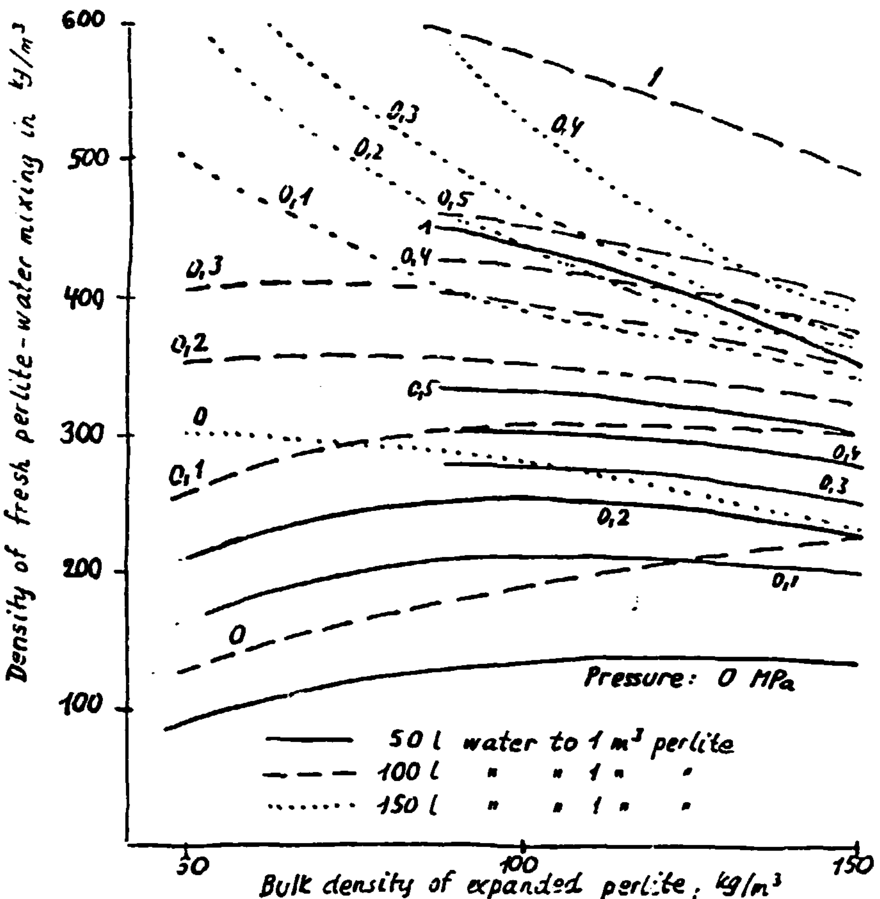


Fig. 13 : Relationship among the bulk density of perlite, the density of compacted perlite-water mixing, the pressure and the water content

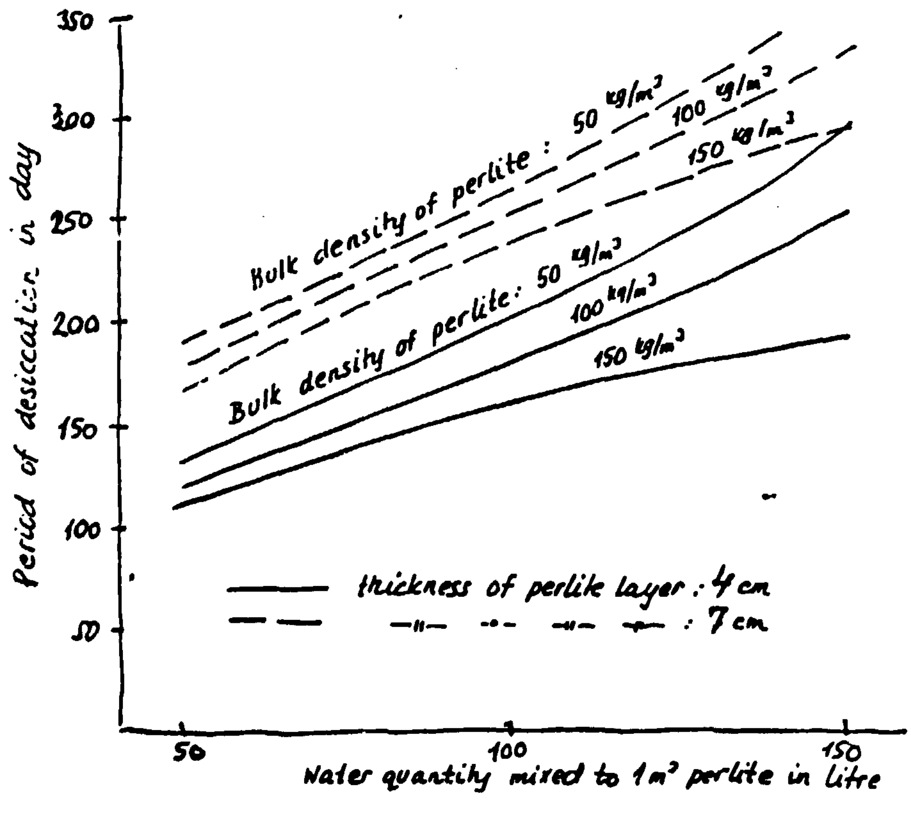


Fig. 14: Period of desiccation of perlite mixed with different water quantity

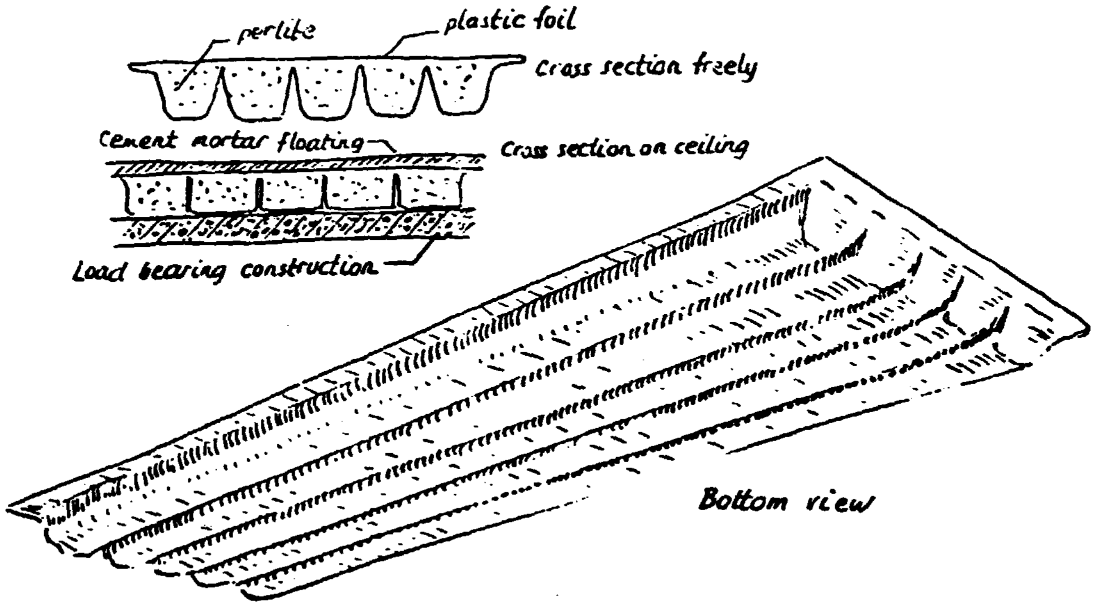


Fig. 15. Perlite quilt

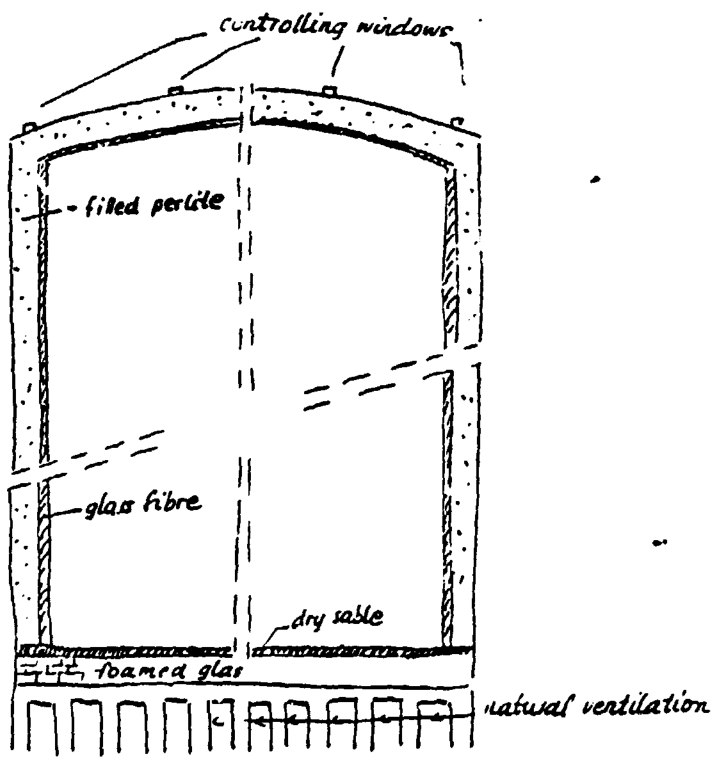


Fig. 16: Cyrogenic tank deep-freezed gas

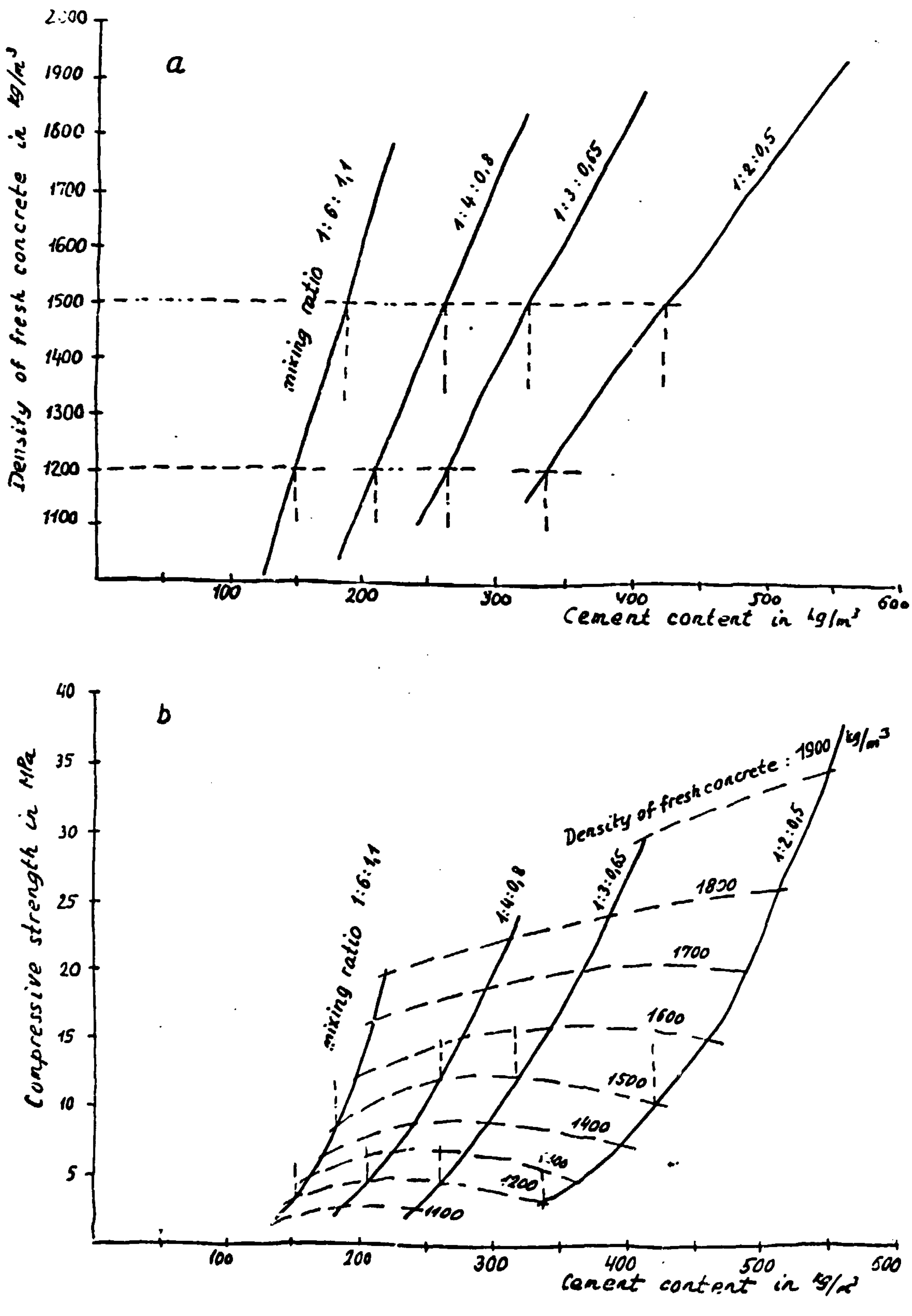


Fig. 17: Designing the relationship among the cement content the density and the compressive strength of the lightweight concrete

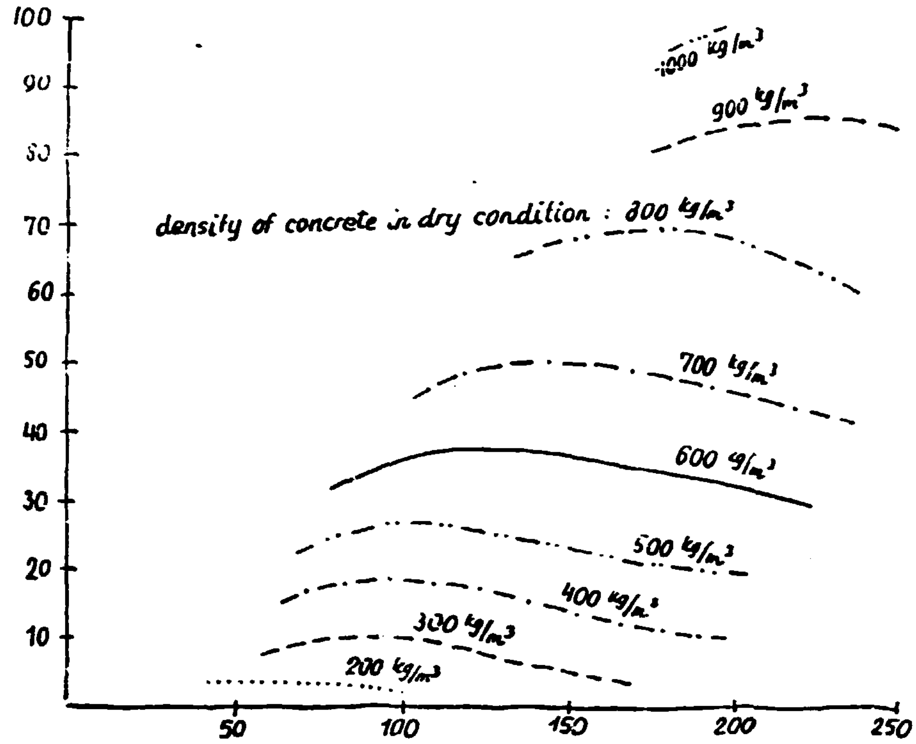


Fig. 18 : Relationship among the bulk density of perlite and the density as well as the compressive strength of perlite concrete

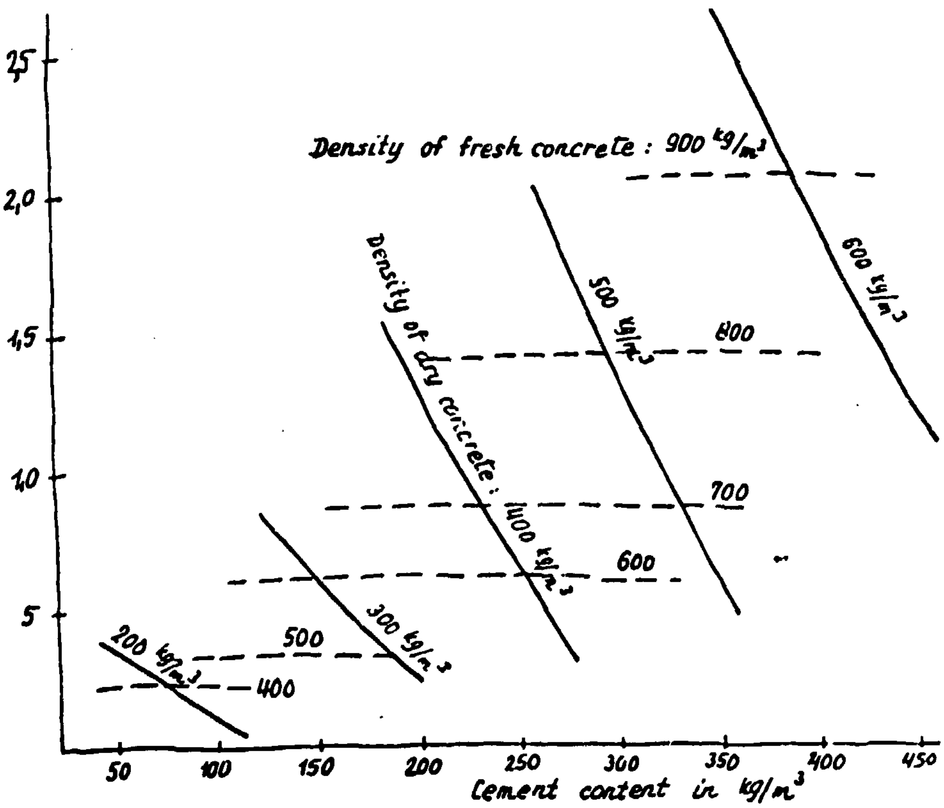


Fig. 19 : Compressive strength and density of concrete made with perlite of bulk density 60 kg/m³ plotted against the cement content

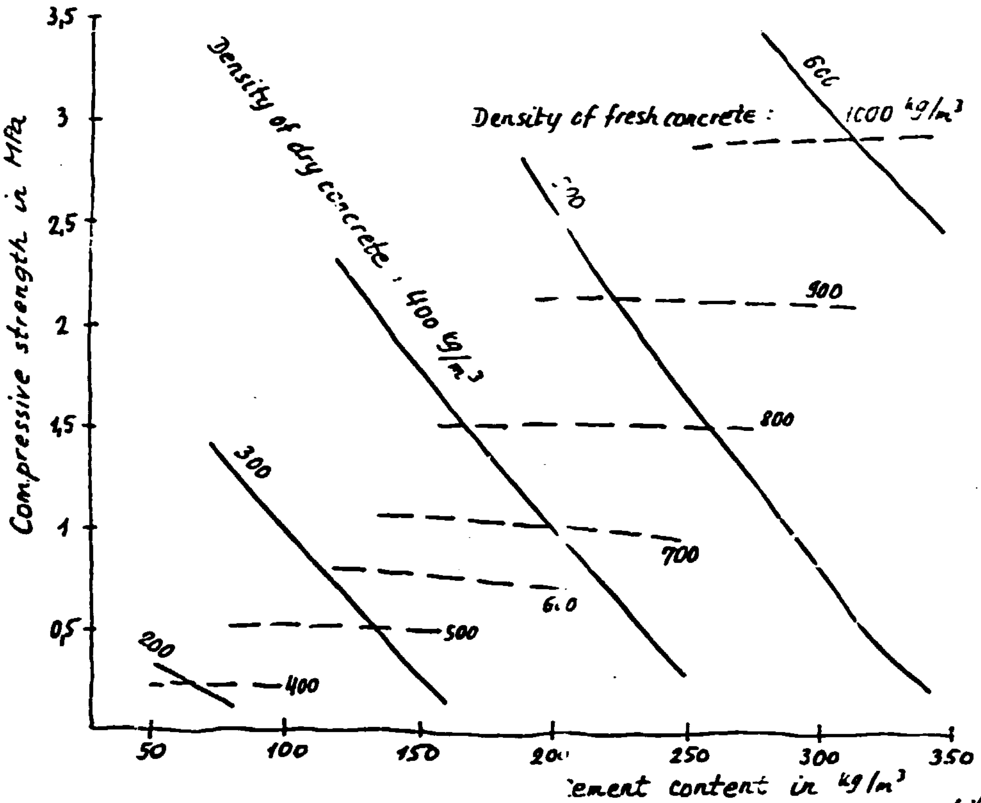


Fig. 20 : Compressive strength and density of concrete made with perlite of bulk density 100 kg/m³ plotted against the cement content

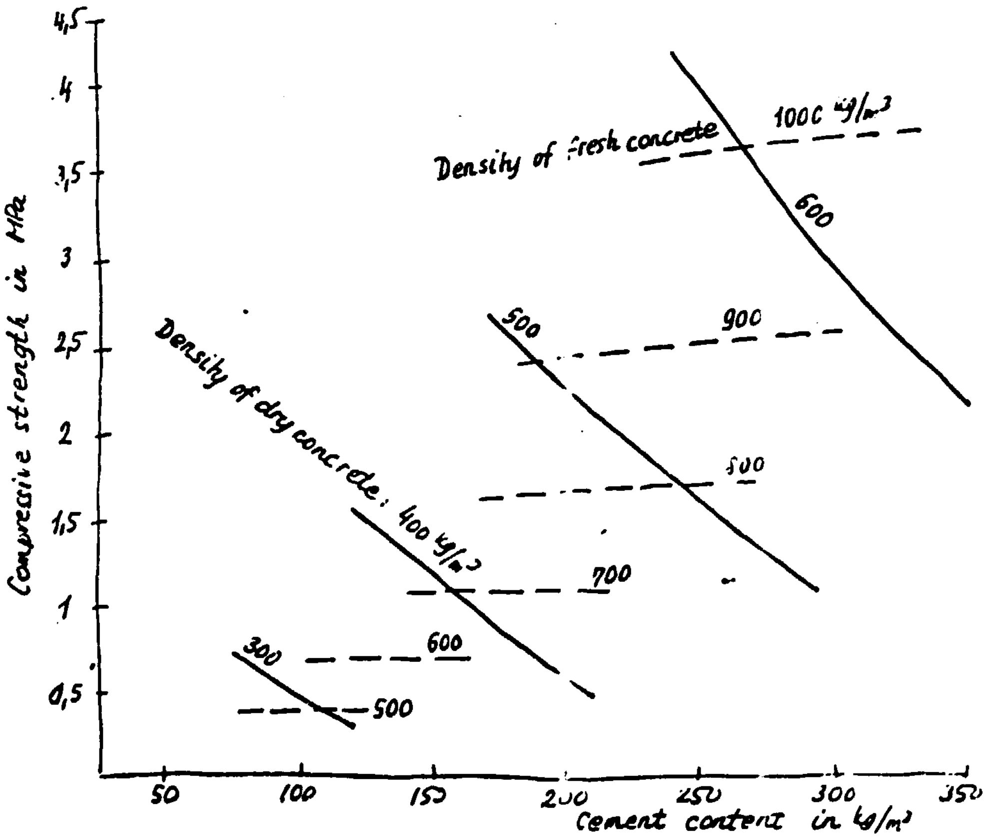


Fig. 21 : Compressive strength and density of concrete made with perlite of bulk density 200 kg/m³ ploted against the cement content

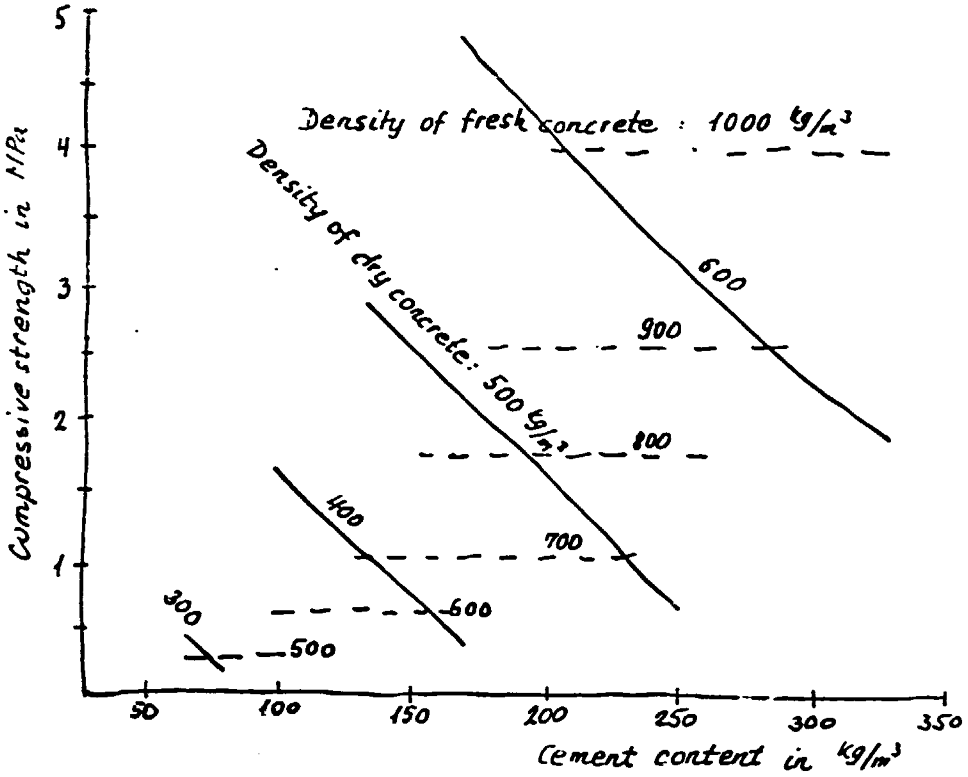


Fig. 22 : Compressive strength and density of concrete made with perlite of bulk density 200 kg/m³ plotted against the cement content

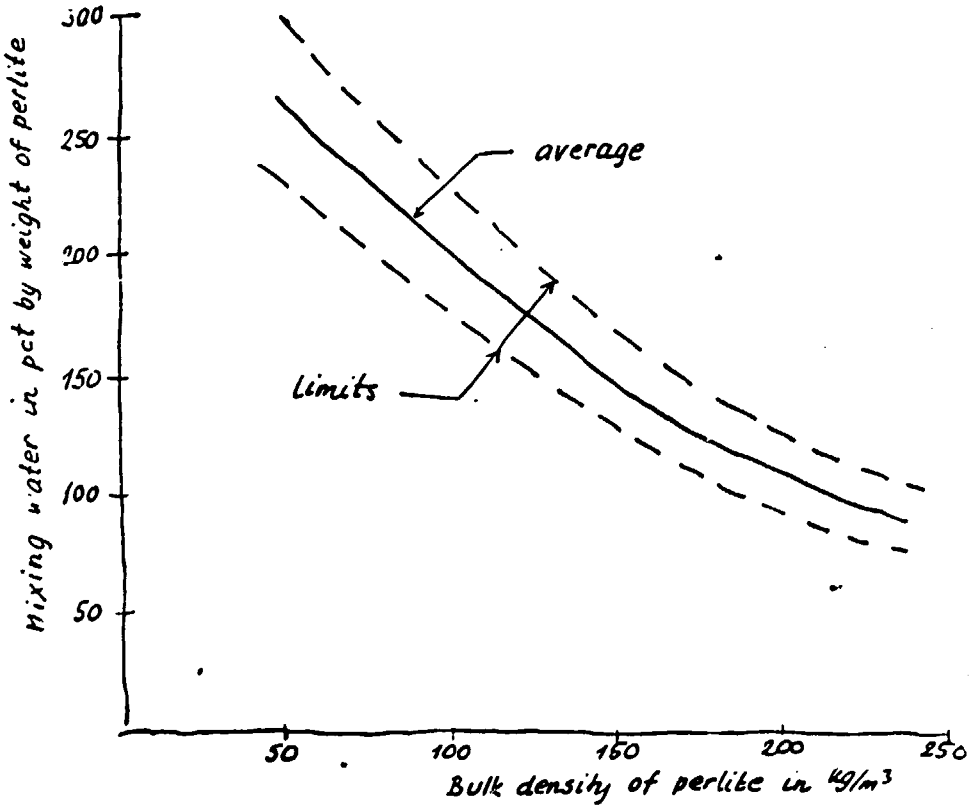


Fig. 23 : Relationship between the quantity of mixing water and the bulk density of the expanded perlite

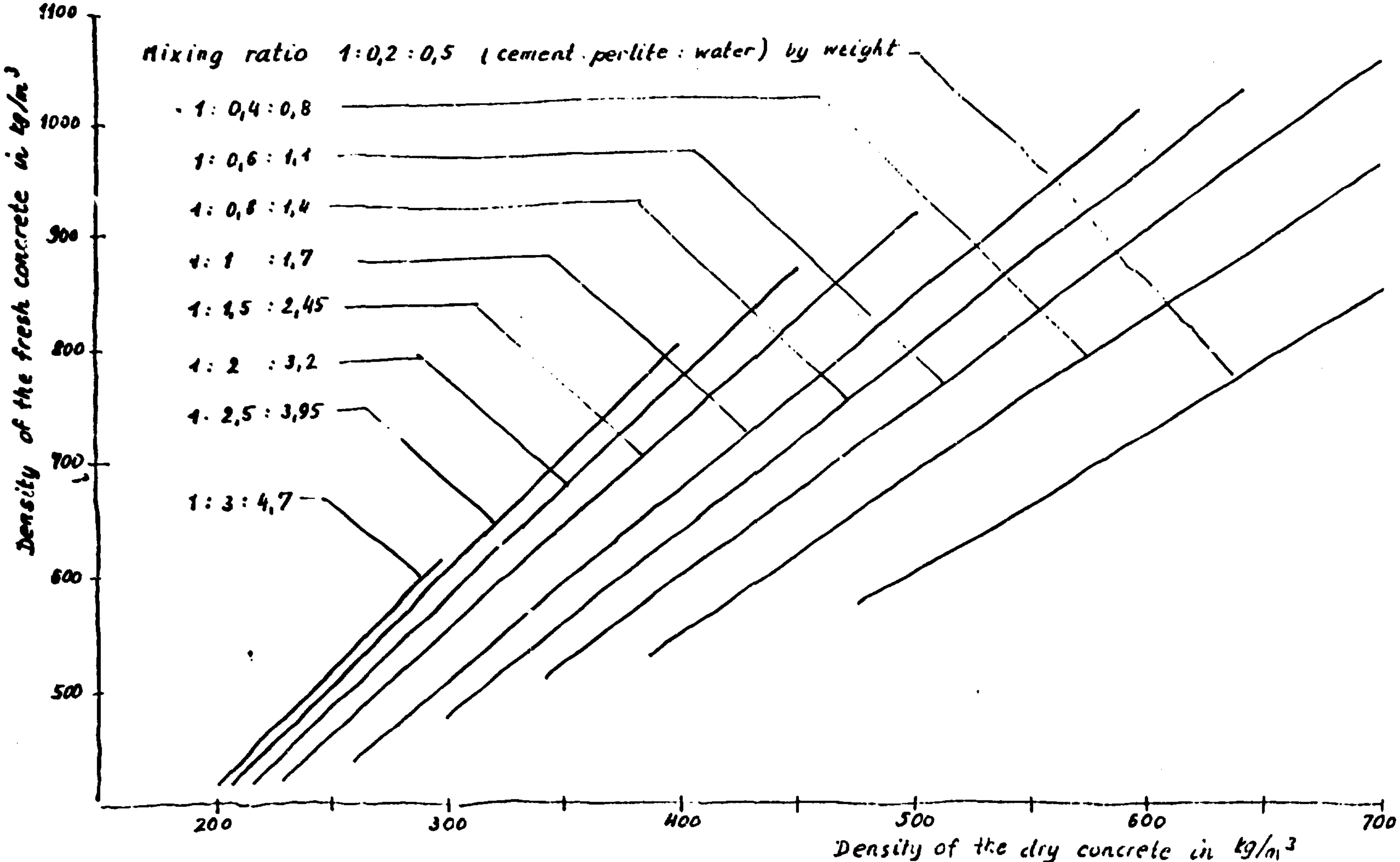


Fig. 24: Relationship between the densities of fresh and dry perlite concrete made with perlite of bulk density 100 kg/m³ depending on the mixing ratio

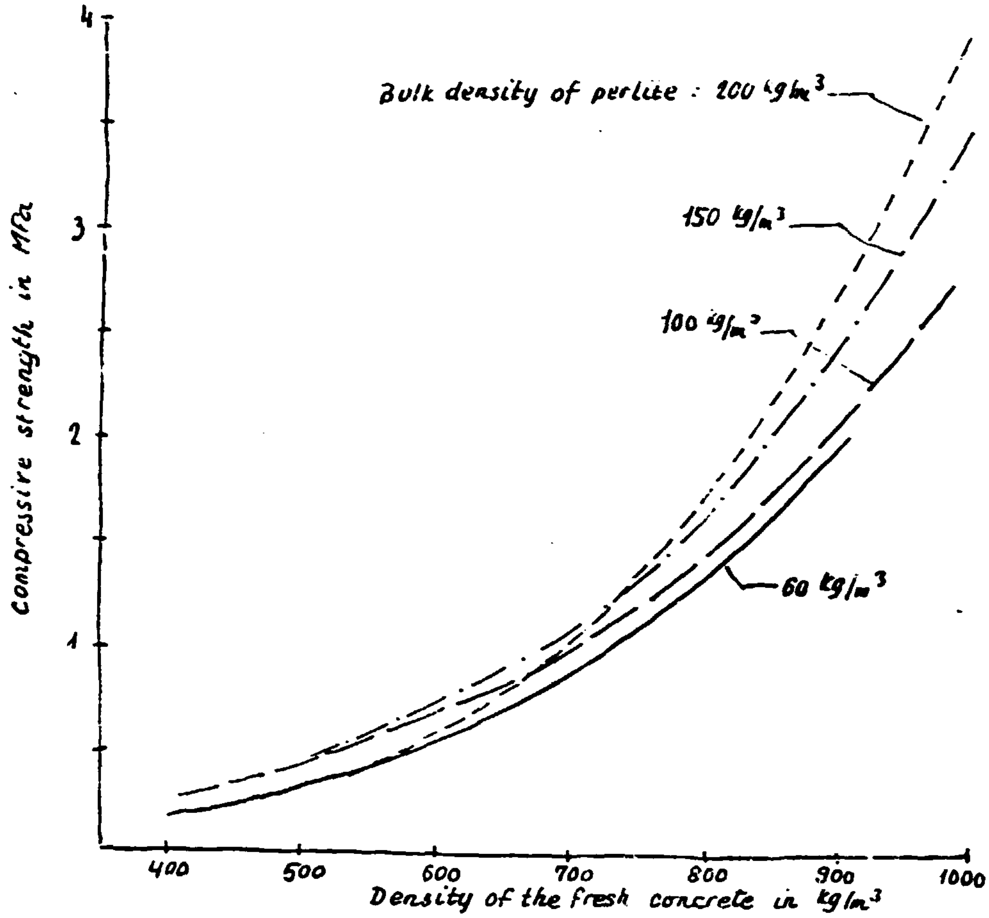


Fig. 25 : The compressive strength and the density of the perlite concrete plotted against the bulk density of the perlite

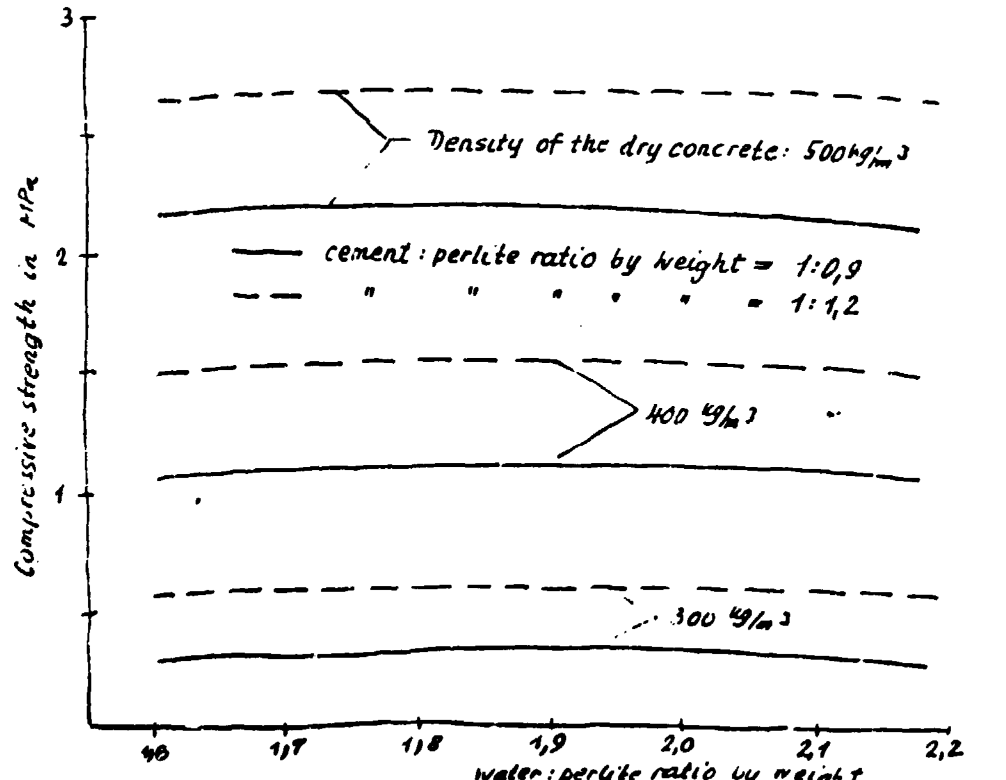


Fig. 26 : The compressive strength and water : perlite ratio of the perlite concrete ploted against the density of the dry concrete

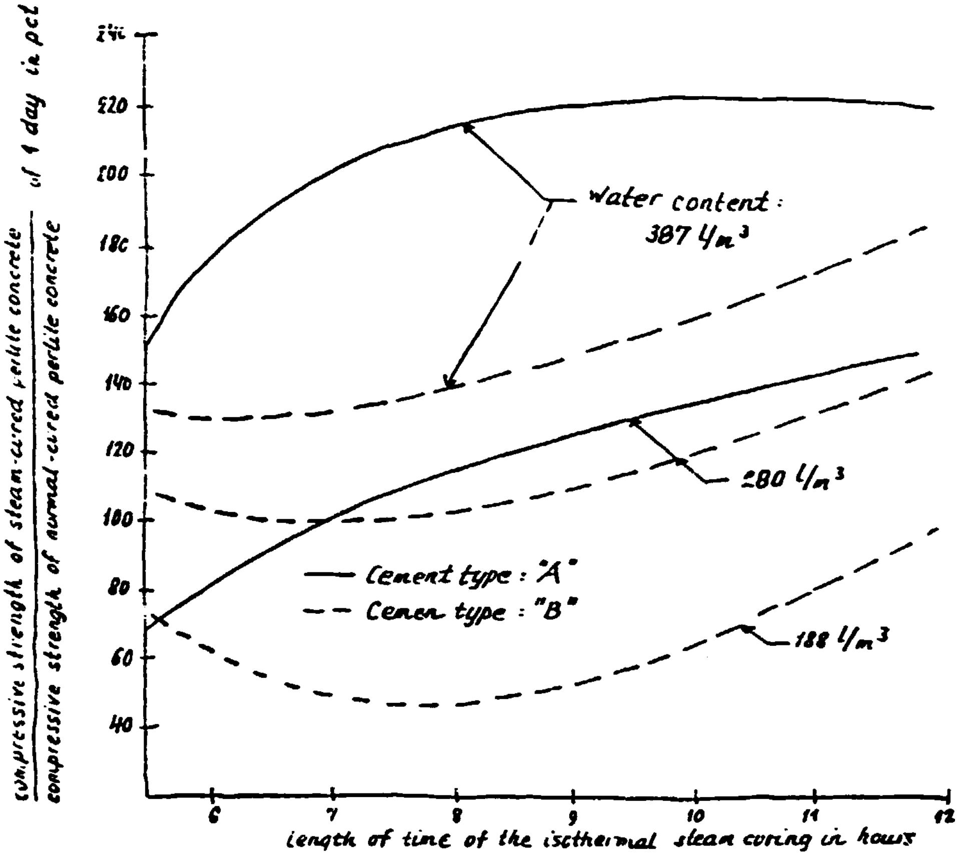


Fig. 27: Relative compressive strength of steam-cured perlite concrete plotted against the length of time of the isothermal steam curing

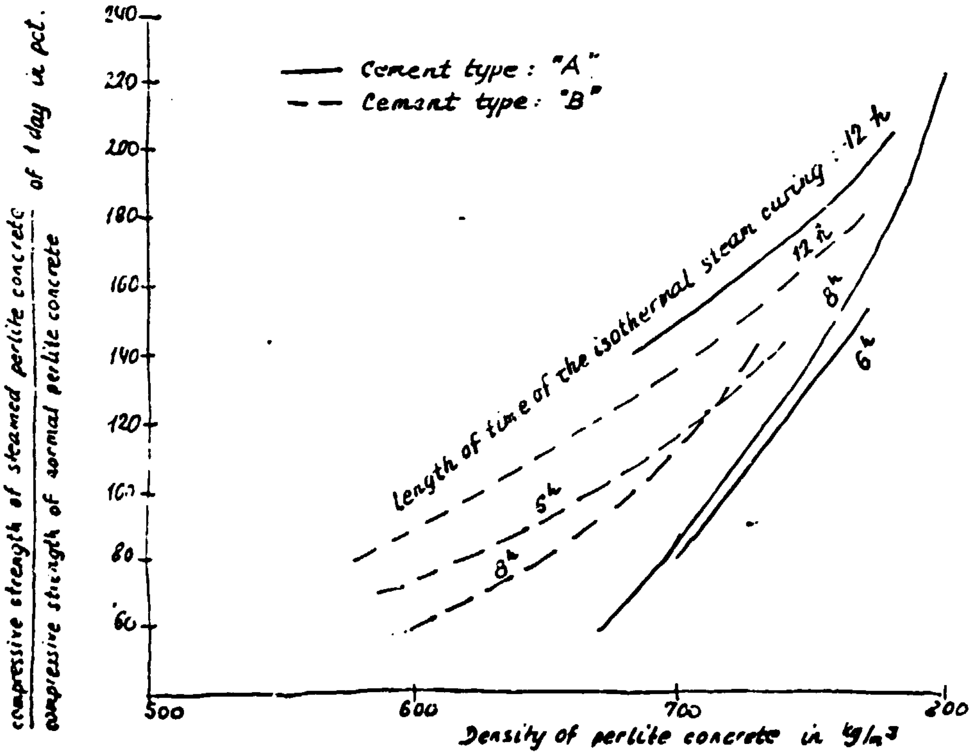


Fig. 28: Relative compressive strength of steam-cured perlite concrete plotted against the density of the dry perlite concrete

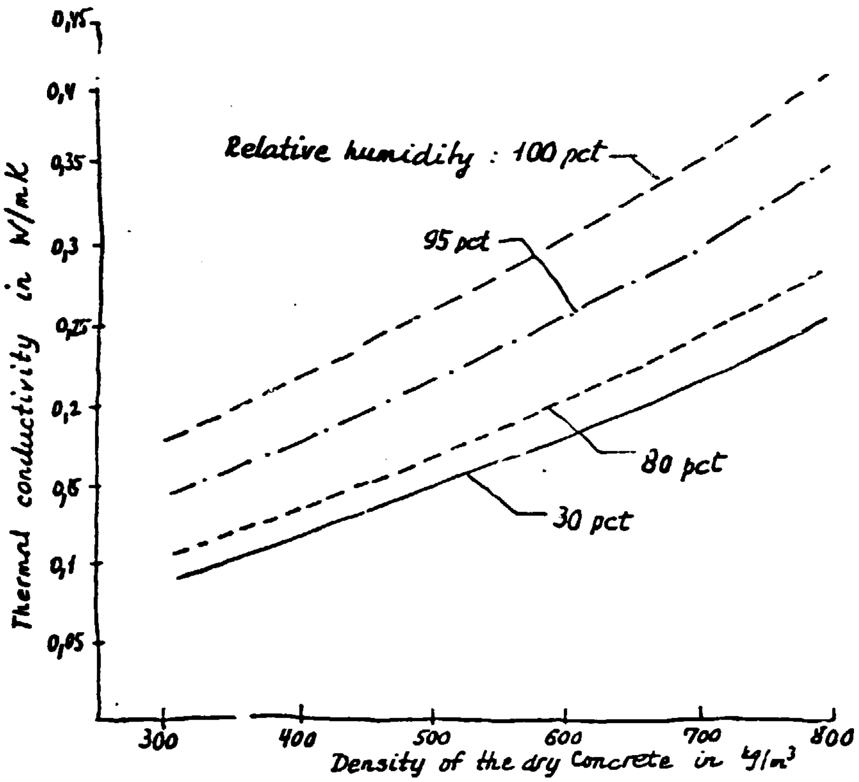


Fig. 29 : Thermal conductivity of the perlite concrete stored by different relative humidity depending on its density

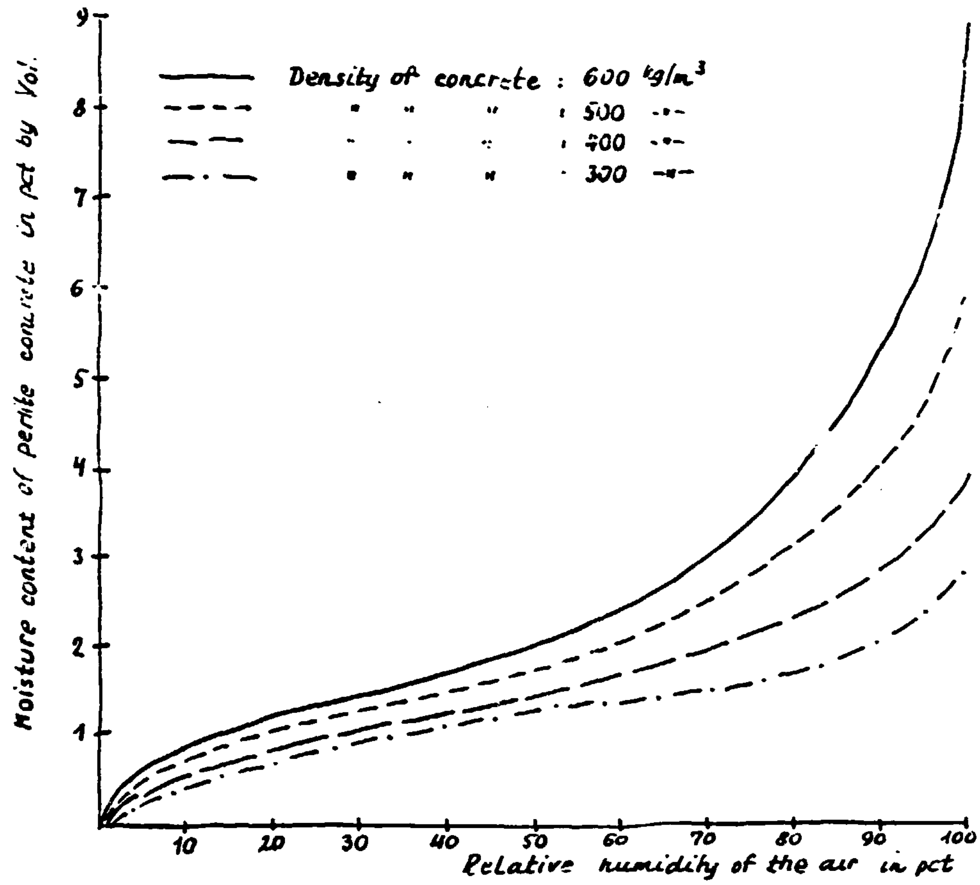


Fig. 30 : Absorption isotherms of the perlite concretes

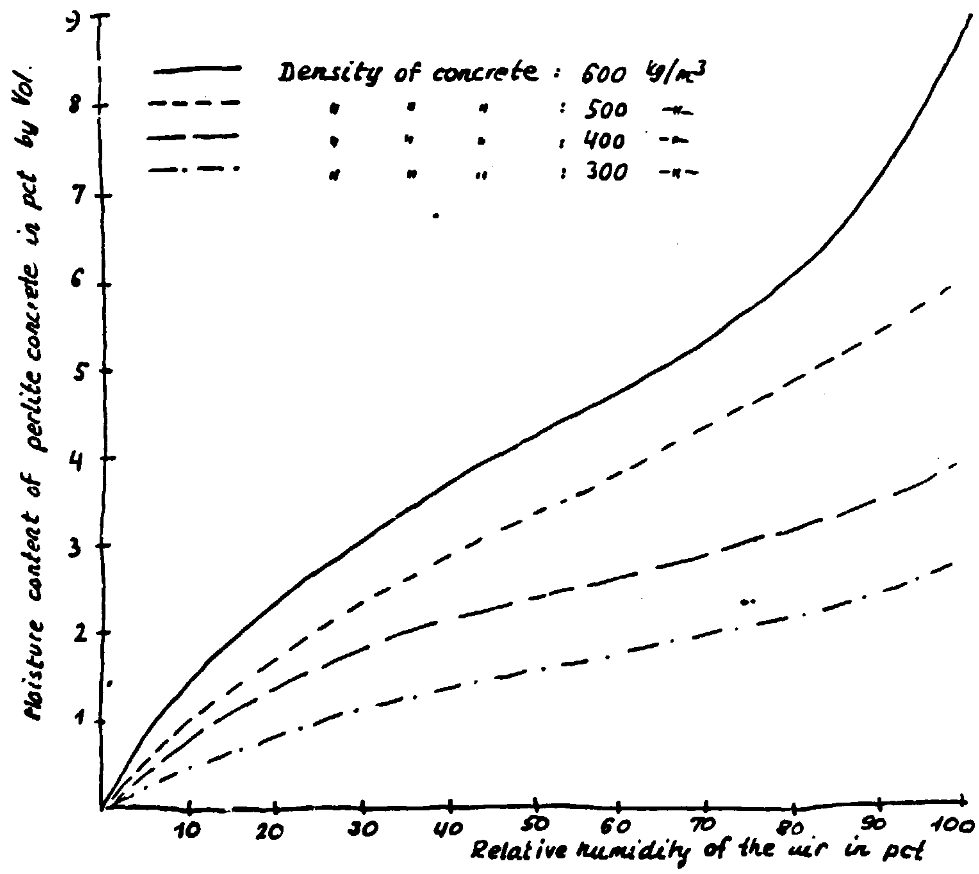


Fig. 31 : Desorption isotherms of the perlite concretes

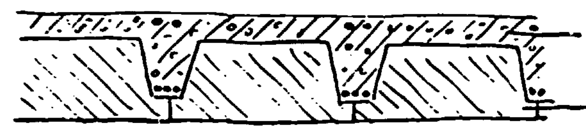


Fig. 32 : Thermal insulation with prefabricated perlite units

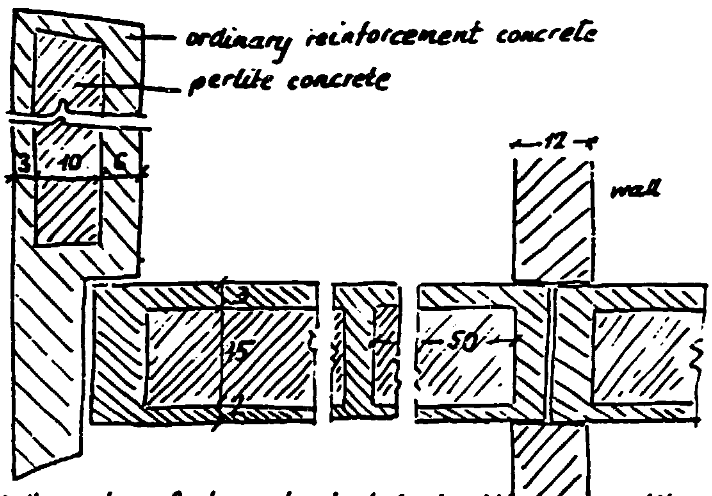


Fig. 33 : Wall- and roof-elements isolated with perlite concrete

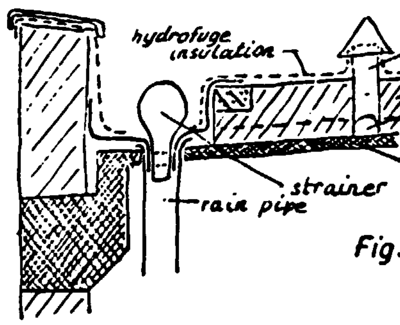


Fig. 34. Thermal insulation on roof shell

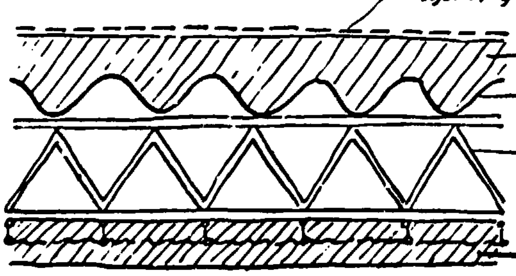


Fig. 35 : Thermal insulation of roof construction in a workshop

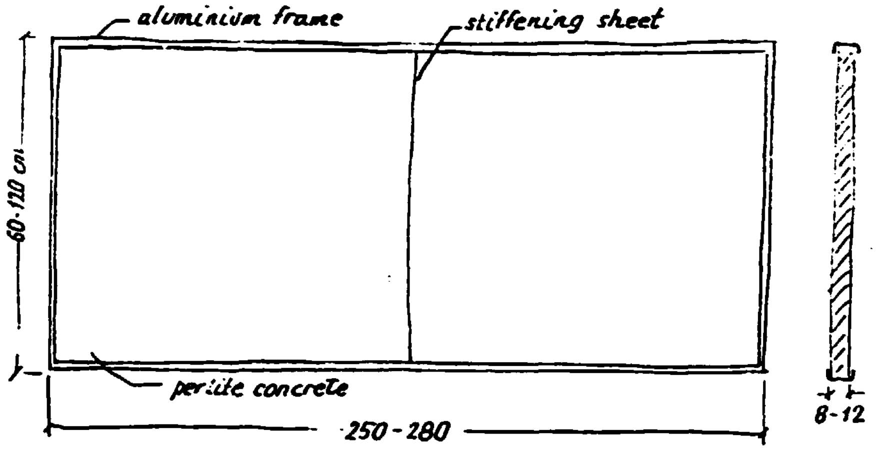


Fig. 36 : Prefabricated perlite concrete wall unit in aluminium frame

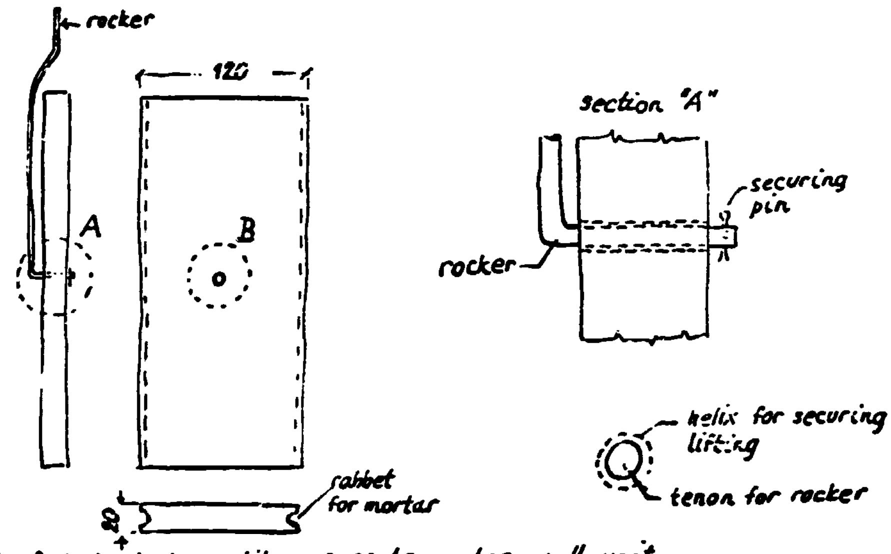


Fig. 37 : Prefabricated perlite concrete outer wall unit

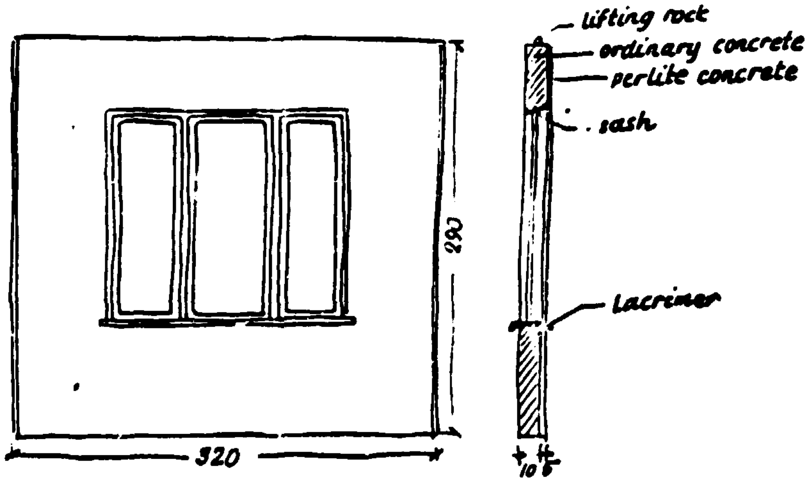


Fig. 38 : Prefabricated sandwich outer wall slab with ordinary and perlite concrete

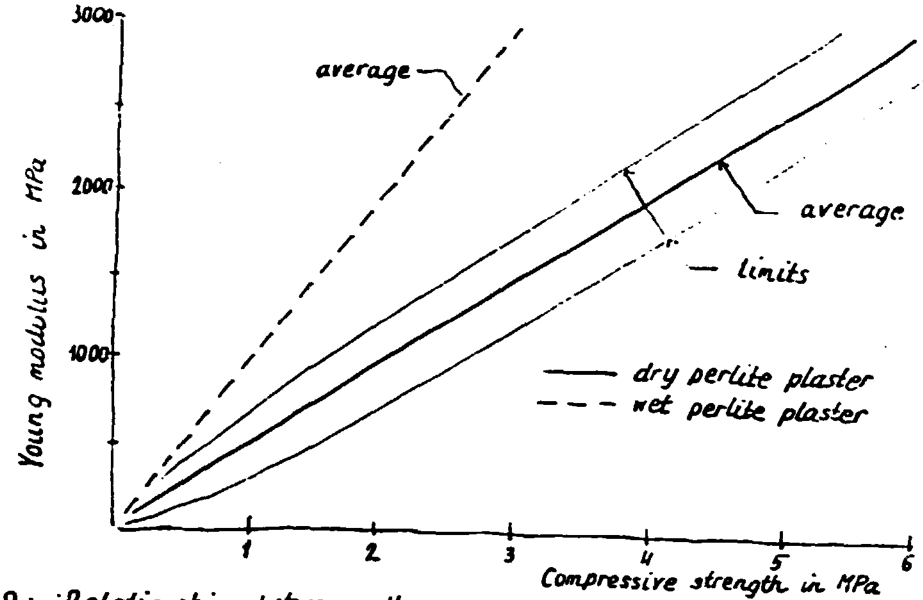


Fig. 39: Relationship between the compressive strength and the perlite plaster's Young modulus

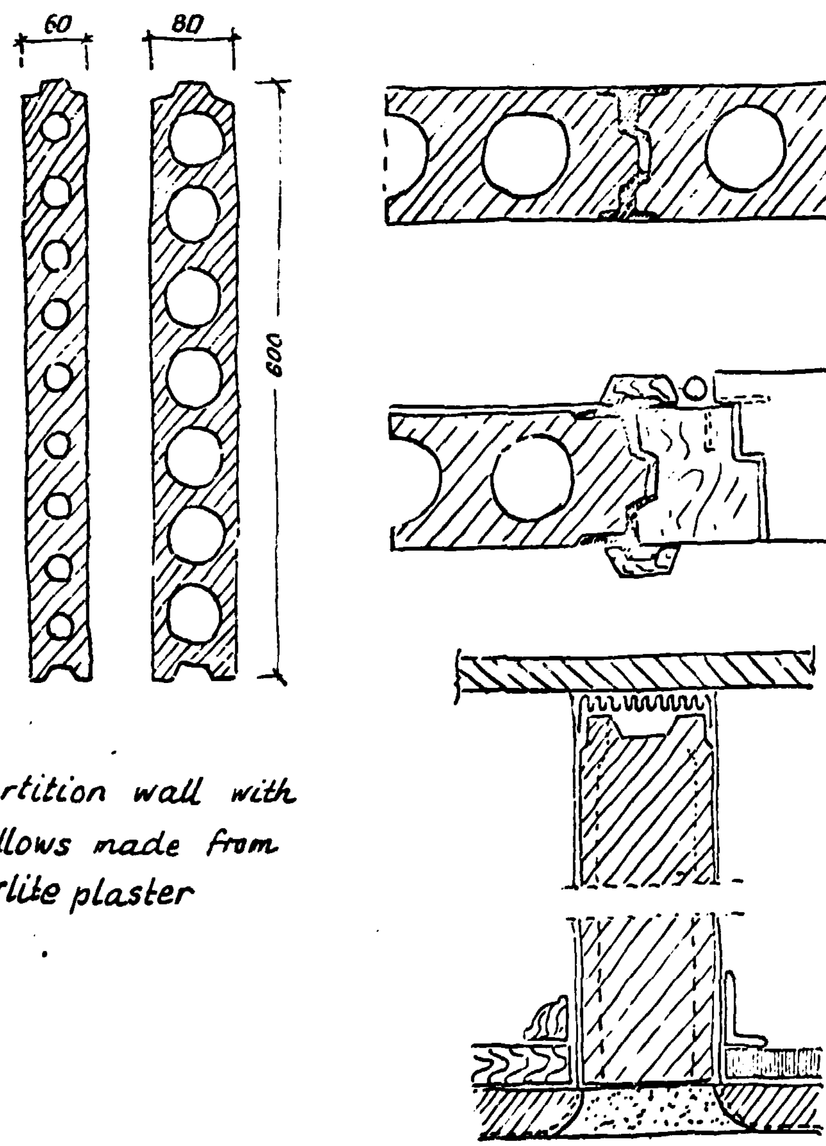


Fig. 40: Partition wall with hollows made from perlite plaster

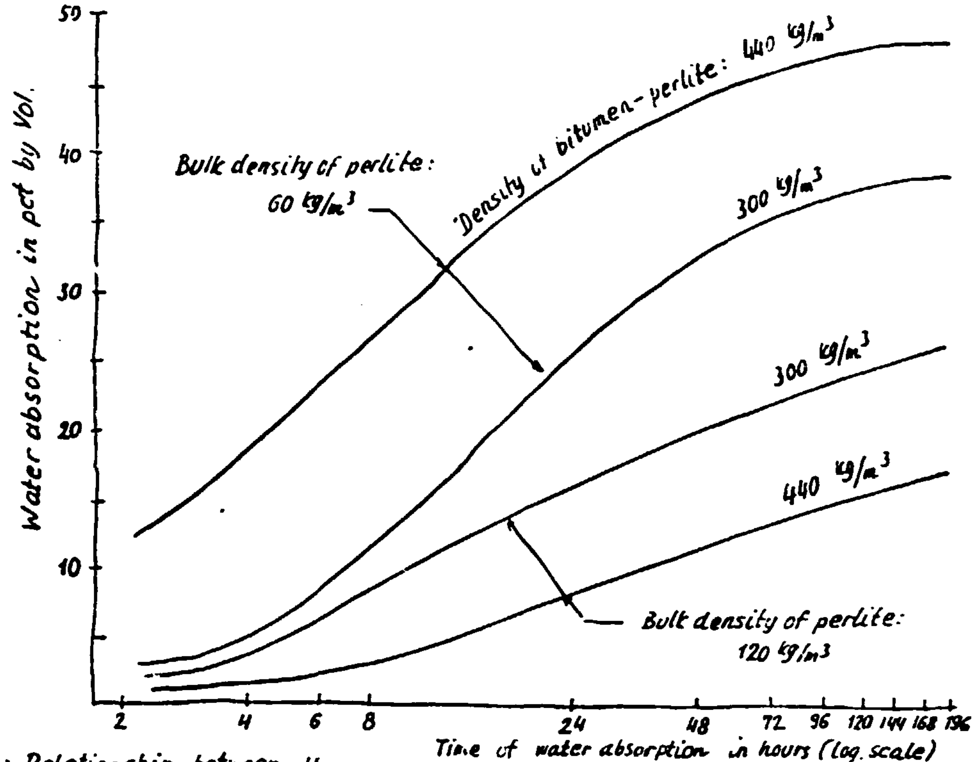


Fig. 41 : Relationship between the water absorption rapidity and the density of bitumen-perlite depending on bulk density of perlite

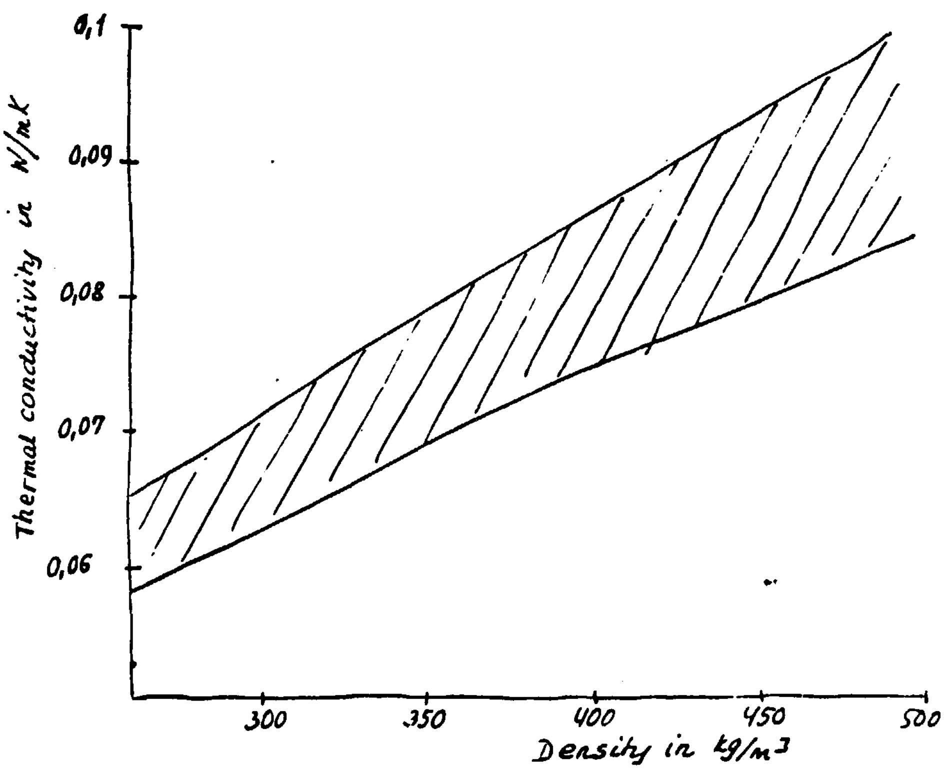


Fig. 42 : Relationship between the density and the thermal conductivity of bitumen-perlite

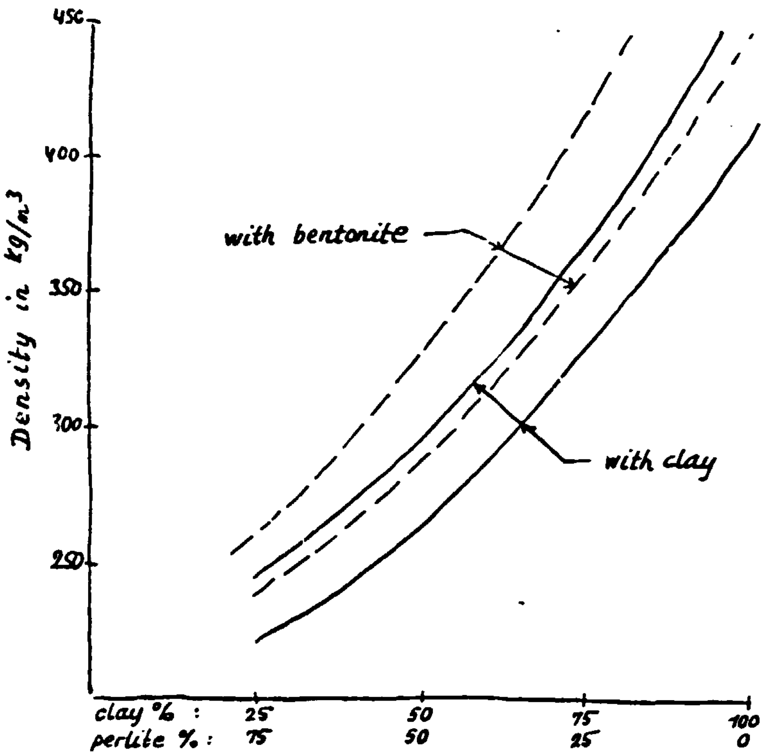


Fig. 43 : Relationship between the mixing ratio and the density of ceramic-bound perlite