Microstructure and Durability Properties of Foam Concrete

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Abstract - *Foamed concrete is a versatile material which consists primarily of a cement based mortar mixed with at least 20-25% of volume air. It is non-load bearing structural element which has lower strength than conventional concrete. Foam concrete is widely used in construction field and quite popular for some application because of its light weight such as reduction of dead load, non-structural partitions and thermal insulating materials. Strength of foam concrete depends upon the foam added. Stable foam production depends upon the type of foaming agent, concentration of foam, method of preparation of foam. In this study the compressive strength of foam concrete was conducted for the specimens. Specimens were made to find out the Suitable foam concentration. In order to increase the strength of foam concrete, test were conducted on specimens with GGBFS as the partial replacement of cement and quarry dust, crump rubber as the partial replacement of sand at varied percentages. The durability and microstructure characteristics are considered for the study of foam concrete properties by varying proportions of constituents.*

***Key Words*: Foam concrete, Durability, Functional Properties, Microstructure.**

1. INTRODUCTION

Foam concrete is concrete classified under aerated lightweight concrete. It mainly consists of cement, fine sand, water & foaming agent. It doesn't include coarse aggregate and can also be known as aerated mortar, foam mortar etc. In addition, cement replacing materials, minerals and chemical admixtures successfully used in foamed concrete. As per ACI 523 1R-06(2006) all admixtures need to be existed together with stable foam within specific mixture [1]. In foam concrete air entrap in mortar is achieved by air bubbles created by foaming agent [2]. Foam concrete have properties like high flowability, low dead weight, very low usage of aggregate, desirable value of strength and excellent thermal insulation properties, acoustic insulation etc. Foam concrete have lower density than normal concrete usually in range of 1600– 400 kg/m^3[3]. Even though, engineering properties of foam concrete is less when compared with normal concrete, it can be effectively applied in low load bearing structures, partition walls, cladding materials in residential building etc. [4]

This paper includes properties of fresh state and hardened state properties of foam incorporated concrete. Functional characteristics such as thermal effect, acoustics properties, effect on fire. Foam concrete discussed on this paper is preformed forming method. Paper also discuss with the pores arrangement on foam concrete and how porosity, permeability, pore size distribution of material depends on strength and durability. [5,6]

Aercrete is broadly divided into two air-entrained concrete and foam concrete. In aerated concrete preparation chemicals, which release gas are mixed with mortar. Chemical reaction take place and gas gets liberated during mixing results porous structure. Pores can be generated by mechanical as well as mixed forming process. It can be achieved either by foaming agent mixed with the mixing water or by foaming agent mixed with the mortar

According to the curing method adopted light weight concrete classified as non-autoclaved and autoclaved concrete. Likewise, according to its density of concrete it can be divided according to the application. Density of the range from 300–600 kg/m^3 is commonly adopted for insulation works and filling purposes whereas from 600–1200 kg/m^3 is used in the production of non-load bearing structures (precast block, panels for outer leaves of building, partition wall, thermal insulation and sound proofing screeds etc.). High-density foam concrete is(1200–1600 kg/m^3) commonly adopted for the making of load-bearing structures [2]

2 MATERIALS

Major components in making of concrete are

2.1 Binder

Ordinary Portland cement, calcium sulphoaluminate cement, high alumina cement, alkali activated cement & rapid hardening cement are used as binding materials. Addition of geopolymer reduce energy consumption and carbon dioxide emission, improve fire resistance property. Cement is partially replaced with flyash, GGBFS, Silica fume in order reduce the high heat transmission by hydration and improve long term strength .Mineral admixtures are replaced by 10 to 75% of cement weight [5]

2.2 Filler Materials

Normally coarse aggregates are not used in foam concrete. Fine aggregates are used and also fine aggregates are partially replaced with different materials like rubber, quarry waste and different graduation of sand(Lim, et al)[7], fine recycled concrete aggregate(Sharipudin, et al.) ,rice husk ash (Hadipramana et al)[8] ,Msand(Yuvaraj, et al) ,Glass fines (Hajimohammadi, et al.),Plastic granules, rubber etc. The plastic granules or plastic fibers are added to light weight concrete gives good result by reducing self-weight. Also, these is an environmental friendly substitution. Adding PET to mortar lead to increase mechanical properties of mortar. It is also found that ratio (1w%) of PET gives desirable strength compressive as well as tensile. While substitution by 7% weight increases flexural strength by 37.93%. Addition of quarry dust also reduces its self weight and is also a good substitution material. According to the study conducted by B.K Meisuh et.al the flexural value of concrete with quarry dust replacement is more than river sand. [6]

Different filler materials such as rubber crump, plastic granules, quarry dust, fiber materials etc. has been used as replacement for the improved features of foam concrete.

Bismark K et.al studied effect of quarry dust on the flexural behavior of concrete. Foam concrete used was mixed by replacing from 25% to fully replacement of sand by quarry dust. Conventional sand concrete prepared as control mix to check the variation of 100 mm cube the flexural strength of concrete prepared by incorporating quarry dust as fine aggregate is about 5% more than the usual river sand concrete. [6]

Awham Mohammed et al [9] studied on the plastic as filler in the concrete.In recent years use of plastic waste in concrete having very high relevancy when we consider resource efficiency as well as environmental protection from waste disposal. Here they studied PET contents of 1%, 3%,5 %, 7%, 10% by weight of cement. 1% weight of cement by plastic found to be better representation of engineering properties. Flexural strength up to 37.93%. is achieved by 7% weight replacement. Adding the plastic waste type (PET) to the cement mortar lead to increase the properties of this mortar at a particular content of PET.

PVC incorporated cement flyash paste with compressive strength above 5 MPa with minimum density is found from the studies. On varying the PVC content from 25-100% (by volume of binder) the strength increased from 5.5-11.6 MPa and density varied from 988.98-1396.46 kg/m3. The PVC addition leads to increase in density and strength.[10]

Huge quantity of waste tyre rubber get disposed in the global wide results in higher emission of smoke by burning and pollution. Dispose the waste tyre rubbery using in concrete mix as a valuable substitute for aggregate at different percentages to obtain good engineering properties of concrete. M. Gesog lu et al.[11] study represents the effect of waste tyre crumb rubber particle of size passing through 1.18mm IS sieve and retained on 600 µ IS sieve used in concrete on compressive, permeability. Permeability coefficient (K) having a range between 0.025 and 0.61 cm/s, which can be used in pavement construction since K ranges in a pervious concrete. Fracture energy of concrete when used with tire chips, coarse crump rubber than fine crump rubber.[12]

Sarika et al. studies replacement of sand with rubber powder decreases density of aerated concrete. Replacement percentage of rubber powder by five percentage replacement of sand results in greater strength to density ratio. Foam concrete with fly ash, rubber powder replacement produces less denser concrete having strength upto 10 MPa. [13]

J. Hadipramana et al. [8] studies rice husk as a filler material in foam concrete it also increased the strength of concrete due to the pozzolanic nature of rice husk ash. S.K. Lim et. Al [7]studied strength as well as toughness with different gradings of sand. Flexural strength compressive strength and ductility will raise with the fineness of sand.

2.3 Mineral Admixtures

Depending on uses, cement can be substitute with flyash, GGBFS, solid waste, silica fume etc. have been added in an optimum percentage to foam concrete. From the studies revealed that GGBS has been added to Portland cement at a level 30% and 50% by cement mass and 20% by mass of cement silica fumes has been incorporated into foam concrete . This was found more effective in enhancing compressive strength of admixture with low % of foam (upto 30%) without effecting air void stability.

Sabari et al's findings says that it is possible to produce light weight concrete with strength up to 25MPa by partially replacing cement by fly ash ,GGBS up to 25%. Also the densities of LWC were in the allowable range of 1600-1400 kg/m^3.When SCM content was increased in the mix, the density found to be decreased due to the low specific gravity of fly ash and GGBS as compared to cement. [14]

2.4 Super Plasticizer

The strength of superplasticised concrete at 28 days is more than that of the reference concrete strength .Concrete depends upon admixture and superplasticiser dosage based on the combination compatibility. However, superplasticiser dosages above saturation level results in bleeding, stiffening and impart the strength with lower value. Cement paste setting can be retarded due to superplasticizer presence, which slows down the rate of hydrating and dissolving ions.[15]

The rheology of cement paste also depends on temperature and superplasticier dosage, it decreases with the raise in temperature at lower dosages of superplasticizer; however, the fluidity increases with temperature the addition of more superplasticizer dosages. This may be due to two compensating mechanisms: the increase in water demand with the shoot up in temperature, and the decrease in viscosity of the cement paste at a higher temperature (or the increase in the efficiency of the superplasticizer with an increase in temperature).[16]

2.5 Foaming Agent

Two methods accepted in construction are, namely, (1) the prefoamed method and (2) the mixing foam method. Foaming agent that are adopted in research works were either chemical or protein made.The protein based foam agents gives increasingly more grounded and firm pore dissemination though the chemical type foaming agents shows more prominent expansionn and along these having lower density. The foam itself has no chemical action in concrete[18] . Synthetic foaming agents are purely chemical products which are stable at concrete densities above 1000 kg/m^3 and enhances good strength. It can be stored for 1 year under sealed conditions without any chemical change. Synthetic foam has finer bubble sizes compared to protein but they generally give lower strength foamed concrete especially at densities below 1000kg/m^3[19]

The preformed foam thoroughly fuse with the base materials produces foamed concrete, are mainly classified into 2: Wet foam and Dry foam. The wet foam is prepared by splashing foaming agent solution and water results in bubbles network of 2 to 5 mm in size. It is relatively more stable with loose bubble usually adopted in synthetically prepared foam mix and not good for lower density structures with density below1200 kg/m^3. The dry foam surface is much closely to a shaving foam with a size less than wet foam. It shows greater solidness and thus stability is more. Synthetic foam shows its effectiveness with handling of and storage span for over 1 year because of the less susceptibility with variation of temperature. Additionally, cost and energy required to is less. Foams based on protein gives higher strength, water holding capacity on protein structure is also more Water from this protein structure further used for the hydration process ensures rigid microstructure properties ASTM C796-04 (2004) [17],[20].Thus, when compared with wet foam stability is more for dry foam. The foam is produced by mixing the foam agent, water and compressed air controlled using compressor machine in desired ratio. The stability of foam agent is discussed on ASTM C 869-91 and ASTMC 796-97 test procedures. The study confirms that it is possible to generate the protein complexes at the boundaries of the interactions of the phases in the silica sol and protein-containing compounds then enhances stability.

Zhihua et al. [21] Studied Foamed concrete with its super low density of between 150kg/m^3 and 300kg/m^3 was prepared by means of synthetic foaming in laboratory. Conventional Portland cement he selected as the main binding material instead of rapid hardening special cement such as sulfo aluminate cement. Admixtures on foam concrete regulates the rheological factors and speed of hardening of the fresh cement mixture slurry, which also enhances the physical properties of the hardened foamed concrete.

Hydrogen peroxide (H_2O_2),a chemical foaming agent is selected to avoid the effects like retarded setting as well as delayed hardening of the paste [39].

Polypropylene Fiber (PF),synthetic Styrene Arylate Emulsion (SAE) , Organic Silicone waterproofing agent (OS), another Foam Stabilizer (FS) were practically used into the cement slurry in order to increases the toughness integrity of volume and resistance water . Thus he concluded that SFC with its dry density between 150 kg/m^3 and 300kg/m^3 can be prepared with Portland cement as binding material and with the optimum percentage addition of ultrafine slag powder and with aid of some physical and chemical admixtures as discussed ,so called mixing and foaming proces.

3. MICROSTRUCTURE PROPERTIES

The pores of the concrete, is mainly influenced by its water porosity, permeability function and distribution of pore size, imparts on its strength and durability [22]. The pore boundary could be a considered as essential factor impacting the quality of this concrete. Void characterization is done on the basis of size distribution, volume,shape and spacing.As air-pocket boundaries explored, volume of foam, size and dispersing have impact on quality of concrete and performance index . Studies indicated that the flyash addition as a filler aide in accomplishing more uniform circulation of air voids than fine sand.

This is on the grounds that fly ash being tiny material, helps in uniform circulation of air voids by giving a well and uniform covering on each air pockets and keeps it from combining and covering where D 90 shows better than D 50 with quality strength ,which indicating that when contrasted the greater size pores have more impact in the ,strength. Mixes with tiny air-void size distribution imparts higher strength. If there should be an occurrence of higher foam volume usage voids will combine and cover each of air pockets appears to create bigger voids, brings about wide orientation of void sizes and results in decrease of strength. As indicated by the investigation of shape on the voids shows that there is no critical effect on the properties of foam concrete as all air voids are of roughly same shape and not reliant of froth volume. When spacing between voids increases the strength and density increase.[12] The microstructure of foam concrete changes, either due to change in composition of filler materials or curing methods adopted. Investigations based on microstructure also proves that, both strength as well as drying shrinkage changes when the microstructure changes. With the inclusion of wastes from industry in the mixes, it unquestionably changes the microstructure, yet those progressions on improvement of properties up to a specific breaking point.[23]

UPV, image analysis and SEM were for the most part used to portray pore structure. Ultrasonic nondestructive is a non-damaging strategy by estimating ultrasonic speed to indirectly assess concrete quality. [24]

Adding pozzolanic powder to foam concrete could reduce the degree of damage. When proportions of pozzolanic powder reached a certain value, the degree of damage increased. At the point when a limited quantity of pozzolanic powder was included, the concrete mortar was completely enveloped by foam. Pore size dispersion will be in uniform manner. Average pore distance across and porosity was diminished. When there was an excessive number of pozzolanic powder added remaining SP and SF didn't hydrate totally with the concrete hydration item in order to break the foam. This expanded fine porosity and came about an raise of ultrasonic velocity and further gets damaged. Including pozzolanic powder could improve its frost resistance. Mass and stress loss arise first and afterward diminished as pozzolanic powder increases. At the point when SP and SF were 30% and 6%, respectively, mass and stress loss get to a minimal value.[25]

SEM analysis indicated that pozzolanic powder could mark down flaky calcium hydroxides, and increased hydrated calcium silicates, so that pore size dispersion was increasingly uniform in manner and average pore diameter also was reduced, the number of connected pores was reduced and the pore walls thicken.

From the studies of Yue Xie et al.[25] they used gel like bentonite slurry along with foaming agent for the study. Compressive quality is seen to be diminished with the expansion in utilization of bentonite slurry in the blend. Insulation properties with bentonite slurry having a satisfactory result. Conductivity with half of bentonite slurry diminished by 29.8% for dry density of 300 kg/m^3.The quantity of the air-voids and the slender pores diminished and expanded with the expansion of BS, separately. The air voids diameter clearly diminished and air-void size all the more barely distributed.

According to the studies by Falliano et al [26], based on the averaged values on eight specimens prepared for each water and air curing condition, the flexural strength in air is increased of more than 130% and the fracture energy is increased of more than 230% compared to the water-cured specimens. Split surface indicated microcracks presence widely in specimen. The pore orientation and allocation is liable for the pattern of cracks. Coalescence effect between neighboring air pockets lead to more extensive cracks and a progressively clear crack pattern. Little and diffused microcracks are watched for air crack surface of the specimens have shown the presence of widespread microcracks. Small and diffused microcracks are observed for air-cured specimens, while less microcracks seen in water-cured specimens.

Sivaraja et. al, (2010) have conducted study on the durability with natural fibres in concrete using coir and bagasse. Studies reported that both natural fibres enhances all the three mechanical strength properties; compressive, splitting tensile of specimen, modulus of rupture of specimen and flexural strength of sample. However, the natural fibres concrete enhanced the strength only at early ages but at later restoring age rate of addition had been accounted for to be lower rate

4. DURABILITY

Durability property of foam concrete can be characterized as its resistence to external interference that might influence or cause deterioration and deflate the serviceability of the concrete lifespan. Safwan A Khedr et al (2006) studied the durability properties of light weight concrete. Light weight concrete shows better resistance to chemical attack in terms of reduced mass loss and or higher number of exposure cycle and less permeability but the abrasion resistance is slightly lower value.[27]

4.1 Resistance to aggressive environmental condition

Foam concrete has high resistance to chemical attack according to the study conducted by Jones and McCarthy. Study reveals foam concrete and normal concrete performance under accelerated chloride has equivalent effect, with enhanced corrosion resistance. Low thickness concrete seems to carbonate at higher rate when exposed to accelerated carbonation [2]. Sulphate resistance of foam concrete, studied by for 12 months [28]

The extension of foam concrete under extreme sulfate condition was seen as 3.75–4.5 occasions higher than that under serious introduction of sulphate condition. This is because of the accessibility of more sulfate for the extensive sulfate reaction.

The XRD analysis delineate that the vast majority of the portlandite was changed over into ettringite which results in the markable expansion what's more, hence the power of ettringite toppeak was generally higher than portlandite top peak for foam concrete exposed to extremely severe sulphate exposure conditions. Expansion of extreme sodium sulfate condition was seen to 28% higher than that under magnesium sulfate with the synthetic forming agent SLS [29].

4.2 Permeability

All permeability indices of increments with a drop in the density (air porousness, oxygen porousness, and water penetrability) [30]. This rate of permeability is faster in foam concrete than in normal concrete (Jones & McCarthy, 2005b; Kearsley & Booysens, 1998; Kearsley & Mostert, 2005b; Kearsley & Wainwright, 2001a; Lee & Hung, 2005). From studies of Kearsley and Booysens (1998) have commented that the oxygen penetrability in foam incorporated concrete with density value a esteem in the scope of 1500 kg/m^3 was lower an incentive than a typical weight concrete with a compressive value having 25 MPa thus, at high densities, foam incorporated concrete could be strong as should typical concrete of equivalent thickness.

4.3 Sorptivity

Moisture transfer occurrence of porous type materials can be measured easily by the property called sorptivity, which is supported by unsaturated flow theory [31].

Water transmission property can be viably clarified by sorptivity than by penetrability. Sorptivity of foamcretes accounted for to be lower magnitude than that of relative base blend and this diminishes with an expansion in foam volume. Likewise, the sorption properties rely on the filler type, pore structure and saturation mechanism. An examination the sorptivity of foamcrete with fine aggregate and fly ash with optimum replacement in the blend reveals fly ash seen higher sorptivity than blends in with normal sand. [31].

5. FUNCTIONAL PROPERTIES

5.1 Acoustic Insulation Resistence

Foamcrete shows higher acoustic protection than typical concrete because of its pore microstructures [36,12]. Acoustic insulation property mainly depends on the thickness of concrete wall and its bulk density. The foamed concrete wall transmits a sound recurrence value up to 3% more than the usual wall.[32] Studies revealed reduced density concrete have multiple times higher benefit of retaining sound contrasted with the denser type concrete.The sound insulation can be influenced by the type of foam used, foam content, amount, size and distribution of pores and its uniformity [33]

Acoustic absorption test is conducted to check the ability of the block to prevent conduction of sound. Experiment is done as per the steps in ISO10534-2[34]

Cylindrical shaped samples of 3 numbers with width as 28 mm and tallness of 50 mm for low frequency waves transmission and Cylindrical shaped samples breadth as 99 mm and height of 50 mm for high recurrence waves are required for each mix. The specimens were kept in an impedance tube and are exposed to low just as high recurrence waves with sound insulation provided for the protection of sound from loss. Sound absorption is then determined and a diagram is plotted with recurrence in the X axis and sound assimilation in the Y axis[35]

5.2 Fire Resistance

In typical concrete, the loss of solidarity is because of very high temperature is affected basically by the constituents utilized. Frothed concrete is noncombustible and its imperviousness to fire is awesome and shows preferable performance over ordinary weight concrete at lower temperatures. This is mostly improved with lower densities

Kearsley and Mostert (2005c) explored the imperviousness to fire of frothed concrete with high alumina content [39]. They saw that the sort of FA, aggregate and content of cement, can impact the imperviousness to fire. Also foamed concrete with Portland cement can face temperatures much as 800°C, the mixtures containing hydraulic cement with an Al_2O_3/CaO ratio higher than 2, can face temperatures as much as 1450°C without showing any signs of damage. .In addition, foam cements with portland alkali based content and at a thickness of 500 kg/m^3 have been demonstrated to be compelling as imperviousness to fire materials with a remaining compressive quality in the wake of starting up to5 times of stronger than before the application of fire(Krivenko et al., 2005). However, at higher temperatures, cement-based foams undergo excessive shrinkage and research is ongoing in this area (Jones & McCarthy, 2005b). Foam concrete shows less plastic shrinkage but the drying shrinkage due to evaporation is very high.[34]Freezing and defrosting opposition of the froth concrete was more noteworthy than the normal worth that acquired from porosity alone. As foam concrete is used as an exterior finish for masonry or frame walls its pores should not filled by water under normal conditions [35]

5.3 Thermal Conductivity Test

Thermal conductivity is the feature of the material in conduct heat. Thermal conductivity test is conducted on a plate shaped samples of size 300 × 300 × 10 mm, as per ISO 8301. The plate is kept at a temperature range of 60 °C and 40 °C as maintained on two sides of the specimens. Time taken for the temperature to be 60 °C on both sides of the plate and their density are noted. Thermal conductivity is then calculated as follows using,[31]

$$k\ ¼ = SeD/DT$$

where,k = conductivity of the specimen, W/Mk:S = sensitivity of flow meter, W/m2V:e = heat flow meter output, V:D = thickness of specimen, m,DT = temperature difference across the specimen, K.[36]

The specimens subjected to high temperature of 200 ^{0}C, 400 ^{0}C and 600 ^{0}C. It tends to be seen that there are no changes with colour shades when warmed at high temperature. Additionally, there were no noticeable cracks on the outside of sample warmed to 200 ^{0}C. In any case, proliferation of cracks was expanded with the expansion in the temperature past 200⁰C, which can be assiciated with the degradation of samples at high temperatures. Density of LWC mixtures (without SF and containing 10%SF) at the ambient temperature of (20 ⁰C) and high temperatures (200, 400 and 600 ⁰C) can be seen that the density of all samples with or without SF was decreased gradually with raise in temperature. The rate of decrease in density was higher when the temperature was increased from the 20⁰C–400 ⁰C. After that, there was a slight decrease in the density of samples when temperature was increased beyond the 400 ⁰C. The performance of LWC samples against the high temperature was assessed by calculating the density ratio (density at high temperature/ density at ambient temperature⁰100). It can be very well watched that density ratio of LWC sample were made for samples containing 10%, 15% and 20% volume of foam and residual density of 87–89% at the 600 ⁰C. Hence, there was a negligible decrease in the density ratio when volume of foam was increased from 0% to 20%. [37]N Vinith kumar et.al observed that almost 50% of the dead load of brick can be reduced. The unit weight of ordinary brick is 1600 kg/m^3 to 1920 kg/m^3, but the unit weight of foamcrete blocks is 900 kg/m^{3}to 1100 kg/m^3.Different density are observed with different percentage of foam added to the mix. Normal water is having a density of 1000 kg/m^3, concrete that floats on water having density lesser than that of water.[38]

6. SUMMARY

Foam concrete is a type of lightweight concrete which consisting of ordinary Portland cement paste filler matrix with a similar void or pore structure brought into by introducing air as of tiny bubbles. Foam concrete consists of cement, fine sand, filler materials, forming agent etc

Foam concrete have some broad properties might be distinguished: (1) high solidarity to-weight proportion that is performance index, (2) lower estimation of coefficient of porousness, (3) lower pace of water retention rate (4) great freeze and defrost resistance (5) inflexible and reinforced microstructure, (6) lower susceptibility towards drying shrinkage , (7) thermally protection property, (8) ought to have great shock assimilation esteem, and (9) acoustic properties (10) Rehabilitation of Floor Structures [39] and so on.In a development of structures made with foam panels diminishes the size of establishments and auxiliary components which helps the reduction of dead load of the tall structures, and in this manner decrease development cost as a whole [40]. The pore structure, shape and size of pores are the principle factor which helps in accomplishing previously mentioned property. The chemical resistance of this type of concrete is also more when compared with normal concrete. Uses of foam incorporated concrete incorporates creation of lightweight squares or blocks and pre-thrown boards, protection insulation purposes, for adjustment of soils stability and stun retaining hindrances in air terminals and customary traffic.[41]. Light weight foam concrete can assimilate acoustic vitality with its permeable structure, arrangement and thickness of foam films, thus it is generally utilized for decreasing noise from the railroad transport.From the investigations, ultra-lightweight foamcements with clear thickness of 100–300 kg/m^3 can be readied utilizing Portland concrete, fly debris, aerating agent and chemical admixtures. Breakdown and air-voids getaway can be maintained by adding foam stabilizers. Pores in ultra-light weight froth concrete are not interconnected pores which helps in lower warm conductivity, successful in its alluring compressive just as rigidity Collapse and air-voids escape can be avoided by and foam stabilizing emulsion into foam concretes. [42,43]

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