LIGHTWEIGHT BUILDING MATERIAL

A Thesis Submitted to

The Faculty of

MICHIGAN STATE COLLEGE

of

AGRICULTURE AND APPLIED SCIENCE

By

HAROLD C. MAC SWAIN

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THESIS

PREFACE

This thesis is submitted to the faculty of Michigan State College as one of the requirements for a B. S. Degree in Civil Engineering.

At this time I wish to express my appreciation to C. L. Allen, Professor of Civil Engineering at Michigan State College, for his assistance throughout the course, and to the manufacturers, whose products are represented, for their help by freely giving the data used in this compilation.

In preparing the material used in this paper, it was the author's aim to collect the lightweight materials that reduce the dead weight in structures, describing their manufacture, properties and uses, no one product being pushed or hindered, but most all the facts being laid out on the table, so the product with the properties best suited for the required needs could be selected from the group, knowing that different needs call for different materials.

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Hedrick-Blessing

RESEARCH AND ENGINEERING BUILDING, A. O. SMITH CORPORATION, MILWAUKEE

Extruded aluminum window and pier con- struction and erection method—also the expansion joint provided at each floor.

CHAPTER I

INTRODUCTION

With the development of a structural-steel skeleton frame in the early eighties, the strain on masonry walls of a building was relieved. Naturally, this made for taller buildings and permitted the use of materials other than masonry in the construction of walls. Since the walls no longer served as a means of support, thinner walls could be employed, thus reducing the dead load.

The skyscraper was designed to make more profitable use of high priced land. By the use of lightweight materials, such as aluminum for metal facades, metal or gypsum interior walls and aerated concrete in floors, the dead weight on a structure is materially decreased with a subsequent saving in the supporting structure, while the rentable area of the building is increased. However, a material reduction in the thickness of walls, unless properly insulated and water-proofed, provides a means for water penetration. As a result, most walls at the present time are made of masonry of 12 to 13 inches in thickness except for some experiments of the use of metal facades. As a result of these experiments it is possible to reduce the thickness of walls 8 to 10 inches. Again, a metal facade can be erected in approximately one-fifth the time required to erect a masonry wall. This results in economies particularly beneficial to the owner. Not only are the erection costs redu

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costs reduced but the saving in time of construction makes it possible to capitalize on the investment in shorter time.

In the construction of a metal wall either extruded shapes or plates may be used for the outer wall. If the inner walls are to be of metal, like materials may be used; or, if a plaster finish is desired, it may be put on a metal lath. A metal wall of this type, with insulating material between the two faces, will be found to have superior insulating qualities to a masonry wall. One test recently conducted showed that a 3½ inch wall of aluminum mineral wool expanded metal lath and plaster had the equivalent insulating value of a 32 inch wall of masonry. Also a double metal wall with two inches of insulating material between the two faces had a heat loss of 0.125 b.t.u. as compared with 0.623 b.t.u. for a 13 inch wall made of brick with a plaster inner surface. The metal wall is about six times lighter than the masonry wall. A 2 to 5 inch double faced wall weighs under 25 pounds per square foot of wall surface as compared with 150 pounds per square foot of wall surface for a 13 inch masonry wall.

The Research and Engineering Building of the A. O. Smith Corporation in Milwaukee, architects, Holabird and Root, has been cited many times for its extensive use of new materials and new methods in both building and equipment.

The building is "U" shaped, having a height of 115 feet and a width of 170 feet; the two wings are 45 feet by 205 feet. The base of the structure is of precast black granite sy

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granite synthetic stone with limestone piers at the corners forming abutments for the saw-tooth type of construction of the metal and glass sections of the front and side elevations.

The V-bay windows formed of extruded aluminum frames and spandrels, the concave extruded pilaster sections of the same material and the buffed aluminum sheet metal cornice illustrate a practical application and use of metal for exterior building facades. The use of aluminum made for greater accuracy, speed and economy.

Although the design and construction of the facade was revolutionary in a great many respects only six days were required to close in the first of the two identical side elevations. Three days were required to close in the second and it is assumed that a similar building could be enclosed in ten days. If masonry walls were used it would have taken fifty days at least to enclose the building. No scaffolding was required in the erection of the aluminum in this case.

A total of 150,000 pounds of aluminum alloy was used for exterior interlocking assembly, cornice flashings, louvres, copings and plinth blocks. A saving of 300,000 pounds in dead weight over a similar assembly of sheet metal of steel. This one item shows how materially the dead weight of a structure can be decreased by use of lighter materials.

Other items of importance that decreased the dead weight of the building was the use of 308 large aluminum windows and 48 triple windows, over 32,000 aluminum screws and bolts and more than 7500 lineal feet of aluminum welding.

This is one example of how a lightweight material was used to good advantage. In succeeding chapters other examples will be given to show their particular advantages in their respective fields.

The material is grouped together so that comparisons of like materials may be made very readily.

CHAPTER II

ALUMINUM AND ALUMINUM ALLOYS

Methods of Manufacture.

The element aluminum was first discovered by a Danish scientist, H. C. Oersted in 1825. The first practical method for obtaining aluminum by electrolytic processes was discovered in 1886 by Charles M. Hall in America and P. L. T. Heroult in France, working independently. The industrial development of aluminum in America began shortly after Mr. Hall's discovery.

Aluminum is found in different forms in clays, soils and rocks. The principal commercial source is the ore Bauxite which is composed largely of hydrated aluminum oxide mixed with impurities, such as compounds of iron and silicon. These impurities are removed by a chemical process leaving the pure aluminum oxide, alumina. By means of an electrolytic process, alumina is reduced to metalic aluminum which is cast into pig form. The pigs are later remelted to form the commercial ingots used in rolling, extruding, and other fabricating processes.

In order to increase the mechanical properties or otherwise alter the characteristics of aluminum, it is often alloyed with various other elements when making the ingots. There are many alloys used, among them, - copper, magnesium, manganese, iron, zinc, and silicon.

Products.

Aluminum in one form of composition or another may be had in many different forms such as bar, casting, cold-rolled, drawn, forgings, hot-rolled, sheets, tubing, wire, extruded shapes, and screw machine products.

The following chart gives the composition of some of the aluminum alloys most frequently used structurally.

		% of Elements						
	A L L O Y	Aluminum	Copper	Magnesium	Manganese	Iron	Zinc	Silicon
WROUGHT	4s	96.0	0.2	0.9-1.4	0.9-1.4			
	3s	97.0	0.2		1.0-1.5			
	17s	92.0	3.5-4.5	3.5-4.5	0.4-1.0			
	25s	93.7	4.5		0.8			0.8
	51s	98.4		0.6				1.0
CAST.	12	91.0	8.0					
	43	91.7						5.0
	195-4	95.0	4.0					

The mechanical properties of 3s and 4s alloy depend upon the temper of the metal which is determined by the amount of strain hardening or cold working given the metal during fabrication. 3s or 4s are ordinarily produced in the following tempers: annealed, quarter hard, half hard, three quarters hard and hard, designated as follows: 3sO, 3s$\frac{1}{4}$H, 3s$\frac{1}{2}$H, 3s 3/4H and 3sH. 3s or 4s can be annealed at a temperature of 800^{o}F.

Alloys 17s, 25s and 51s are known as strong alloys. Their maximum mechanical properties are produced by heat-treatment followed by proper aging, and when they have been treated they are designated as 17st, 25st and 51st. In 17s alloy the aging takes place spontaneously at room temperatures following heat-treatment, and hence this alloy cannot be kept in the unaged condition or W as this condition is designated. 25s and 51s, however, are aged artificially at a higher temperature and hence may be produced in the heat-treated condition without being aged, being designated as 25sw and 51sw, their properties being somewhat lower than in the fully-aged or T condition. The strong alloys can be annealed after heat treatment by holding them at a temperature of 800° F. for at least one hour, after which they are very slowly cooled to below 500°F. In the annealed condition the strong alloys are designated 17so, 25so and 51so.

The wrought alloys 17s, 25s and 51s are heat treated to improve their structural value. Alloy 17s is heated to a temperature of 940°F. to 960°F., while alloys 25s and 51s are heat treated to a temperature of 960°F. to 980°F. The time required in heating is the same for all three alloys, being 15 to 60 minutes. A quench in cold water with the minimum loss of time is required of all three while the aging temperature and time of aging are different for each of these alloys. 17s requires room temperature for aging for a period of four days, while 25s requires a temperature of 285°F. to 295°F. during an aging period of 8 to 15 hours and 51s is aged 18 hours at a temperature of 310°F. to 320°F.

The casting alloys are designated by numbers only as 12, 43, and 195-4 etc. 195-4 is different from other casting alloys in that it is heat treated to improve its mechanical properties. The heat treating consists of approximately 12 hours of heating at a temperature of 960°F. with a quench in hot water.

There are many other alloys produced commercially and experimentally but these alloys given are a good representation of the aluminum alloys used structurally.

Weight.

The weight of aluminum alloys is about 173 pounds per cubic foot, which is approximately 1/3 the weight of steel which is commonly taken as 490 pounds per cubic foot.

The weight of 24 gauge aluminum sheet metal is 0.283 pounds per square foot as compared with 1.0229 pounds per cubic foot for stainless steel.

Aluminum, wherever used in place of other metals, will materially reduce the dead load which is an important factor of design in many cases.

Structural Value.

A design stress of one-fourth the ultimate strength is recommended for simple axial tension and tension on the extreme fiber. When the yield point exceeds one-half the ultimate tensile strength, a design stress higher than one-half the yield point or one-third the ultimate tensile strength.

Compressive design stress for bearing, bending and short columns is usually taken as one-third the ultimate compressive strength except in the case of annealed material in which case one-fourt the ultimate compressive strength is used. Simple axil compression on short stiff members and for compression on the extreme fibre in bending, one-fourth the ultimate strength is used in design with the same exception for alloys of high yield point as was made for alloys in tension.

As in any other material, slender members that are not restrained against sidewise buckling cannot sustain high compressive stresses. Therefore, long column compression members have a variable compressive stress for safe design. There are set formuli for different slenderness ratios and different end fastenings. These formuli are derived at by experiments.*

Shearing design stresses should be taken as one-fourth the ultimate shearing stress without any limitations.

The modulus of elasticity of steel is 29,000,000 pounds per square inch while the modulus of elasticity of aluminum is 10,000,000 pounds per square inch which means that under the same loading aluminum will deform 2.9 times as far as the steel.

*For Formuli and Constants, see page 19 of Alcoa Structural Aluminum Handbook.

MECHANICAL PROPERTIES OF ALUMINUM ALLOYS

	ALLOY and TEMPER	Weight lb.per cu.ft.	TENSION			COMPRESSION		Shearing Strength lb. per sq. in.	Endurance lb.per sq. in. (Rotating Beam)	Brinell Hardness No (500 kg on 10mm ball
			Yield Point lb.per sq.in.	Ultimate Strength lb. per sq. in.	Elongation in 2In per cent.	Yield Point lb.per sq. in.	Ultimate Strength lb. per sq. in.			
WROUGHT	3SO	171	5,000	16,000	40	5,000	16,000	11,000	6,000	28
	3S½H	171	18,000	21,000	20	18,000	21,000	14,000	9,500	45
	3SH	171	25,000	29,000	10	25,000	29,000	16,000	10,500	55
	17ST	174	35,000	58,000	20	35,000	58,000	35,000	15,000	100
	25SW	174	25,000	48,000	18	25,000	48,000	30,000	14,500	80
	25ST	174	35,000	58,000	20	35,000	58,000	35,000	15,000	100
	51SW	168	2,000	35,000	24	25,000	35,000	24,000	10,500	64
	51SW	168	35,000	48,000	14	35,000	48,000	30,000	10,500	95
CAST	12	178	14,000	22,000	2	16,000	38,000	20,000	8,500	65
	43	166	9,000	19,000	4	9,000	25,000	15,000	6,500	40
	195-4	174	16,000	31,000	8	27,000	43,000	27,000	6,000	65

This deformation may be easily overcome by the use of a deeper web in the beam. Take for example a steel 18 pound I-beam rolled section of 8 inch depth with a web of 0.270 inches over a span of 10 feet 0 inches c. to c. and a uniform load of 1200 pounds per linear foot of beam. The maximum deflection is found by the formula -

$$\Delta = -\frac{5}{389} \times \frac{W\,(l)^3}{E\,I} \text{ to be 0.163 inch.}$$

Now take an aluminum beam of same cross-sectional area namely a 6.53 pound I-beam of 8 inch depth and a web thickness of 0.270 inches. Maximum deflection is found to be 0.468 inches. The nearest aluminum beam that will cause a deflection less than 0.163 inches is a 12 inch I-beam with a weight of 11.31 pounds per lineal foot and a web thickness of 0.350 inches. This all goes to show that for a span of 10 feet 0 inches c. to c. and a uniform load of 1200 pounds per lineal foot it would take a 11.31 pound aluminum I of 12 inch depth to equal the deflection caused by the same loading over the same span of an 18 pound steel I of 8 inch depth. If the head room required was not important but dead weight was, it would pay to put in the larger aluminum beam, for although 4 inches is added to the head room 6.69 pounds per lineal foot is cut from the dead weight or 66.9 pounds for the 10 foot span. Increasing the depth is not the only means of cutting the deflection, as any way to increase the moment of inertia of the aluminum section so it will be about 2.9 times the moment of inertia of the steel section will make the two sections deflect an equal amount.

The temperature for which the design stresses have been given is 100° F. and below, which is the temperature that structures are subjected to under ordinary conditions. Above the temperature of 100° F. the strength of aluminum and its alloys decreases. This is not common alone to aluminum, as other metals react similarly under the same conditions.

The coefficient of expansion of the aluminum alloys averages about 0.000013 inches per degree F. which is more than steel. One might think that it is inadvisable to use steel and aluminum together for reason of their differences in the coefficient of expansions but temperature stresses are not necessarily severe. Aluminum plates have been used in direct contact with steel fastened by rivets and without any serious effects.

Experiments conducted to determine whether impact stresses were any different in aluminum than steel showed that impact was no more severe on aluminum than upon steel, therefore, the same practices should be followed as in steel for impact stresses.

<u>Durability.</u>

Aluminum and its alloys will not corrode or rust and when properly designed they have the strength necessary for their requirements. The metal may be left as erected or it may be painted with a little preparation either by a sand-blast or a chemical bath. Direct contact with excessive heat causes weakening of the structural value of the metal which is likewise the result in the case of other metals.

<u>Insulation.</u> - (a) Heat and Cold.

The metal is not often used alone for an insulating wall but is used with some insulating material and lath and plaster, or, if metal partitions are being used it is a simple matter to back the insulation with a second sheet of metal, either aluminum or any other metal that happens to be used on the interior walls of the building.

A recent test upon a 3⅜ inch wall of aluminum, mineral wool, expanded metal lath and plaster, showed an insulating value of 0.26 b.t.u. which is equivalent to a 32 inch masonry wall. Another test showed that a 2 inch wall composed of insulation between two faces of aluminum had a heat loss of 0.125 b.t.u. This type of a wall weighs less than 25 pounds per square foot as compared with 150 pounds per square foot of a 13 inch wall.

(b) Sound Insulation.

For inner partitions, aluminum walls are constructed as outside walls; that is, two sheets of aluminum with insulation between,the sound-proofing is very effective although reverberation is increased by the smooth surface, therefore, its best use is found in office buildings.

(c) Fire.

As stated before aluminum decreases in strength with a temperature above 100° F. Therefore, it is not a fire resistant product. Walls using the metal can easily be made fireproof by placing a fire resisting material between two sheets of metal forming the wall surfaces.

(d) Dampness.

Aluminum is impervious to dampness as are other metals. It is fabricated by flanging, riveting or welding, so an impervious joint can easily be made.

In the all metal office building of the Department of Public Works in Richmond, Virginia, aluminum pilaster columns, shop assembled, were used which consisted of a frame of extruded sections of 1/8 inch plate. They are 25 feet high, 3 feet wide and weigh approximately 250 pounds. The vertical members of the frame are one piece, thus simplifying fabrication of the column as a whole. The joints between the horizontal and vertical members are welded. The panel sections, 6 feet in length, fit into grooves in the molding. The four sections are tied together by means of counter sunk aluminum bolts through a 1 inch offset at the top of each of the three lower sections. A piece of aluminum sheet, welded on the back of each of the upper plates, fits over the offset joints and completes the water seal.

The steel sash are anchored at the jambs to structural steel angles which form a supporting frame for the attachment of the sheet aluminum interior columns and the exterior trim as well as the exterior sash. The exterior trim between window columns and pilasters consists of satin-finished aluminum sheet.

The building is capped with a 3 foot 10½ inch paneled entablature, using the same extruded sections that were used in forming the pilasters. These are 10 feet long attached by steel clips to structural colunns. Sheets are connected at junctions by welding and supported underneath by a wood block covered with sheet aluminum.

Workability.

Aluminum and its alloys are fabricated by any of the following methods: deep drawing, flanging, riveting, welding and spinning. It is possible to use aluminum and its alloys in any of the forms known to the metal working industry.

Uses.

Aluminum is available in all the forms useful to the building industry; namely, bar, castings, cold-rolled, drawn, forgings, hot-rolled, sheets, tubing, wire, extruded shapes, and screw machine products. A few of the places where aluminum can be used in a building are metal roof, ventilating ducts, window sash and frames, spandrels, mullions, stair-

railings, risers, treads, and balustrads, elevators, doors and frames, store fronts, etc.

In Germany the Junkers Company is experimenting with different kinds of shops having built two identical workshops except one is built of masonry and one of metal. In the masonry structure they used steel doors while in the metal structure they used aluminum doors. On one of the large doors an additional saving was experianced by the use of aluminum. The steel door weighed about 1000 pounds and had to have a special operating device to open and close the door, while the aluminum door weighed slightly over 300 pounds no operating device was necessary, the door being operated very easily by hand.

The New U. S. Botanic Garden in Washington, D. C. is of special interest and importance because of its extensive use of aluminum for structural members, this being the first large structure in which aluminum was used for this purpose.

Aluminum alloy was used mainly to reduce maintenance, cleaning and painting. The lofty portions are subject to hot moistures necessary in the palm house which would make corrosion take place very readily if steel were used in these places. In the palm house the columns are of steel; the cantilevers, central suspended trusses and all purlins are of aluminum. In the two side bays of the palm house the curved heads of the columns are aluminum, the columns being steel. Aluminum is also used in some of the roof trusses in the lower parts of the structure. Sash bars or glazing bars are of aluminum throughout the building.

The specifications of the aluminum called for four kinds of alloys - 4s 1/8h or 1/4h was required for purlins and ridges channels while 17st was specified for the other shapes, plates, rivets and bolts. Glazing members and extruded members were made from 3s$\frac{1}{4}$h and 43 alloy was used for the castings. This gives a view of an actual application of these different alloys showing the places where they are used.

The building is a hollow rectangular building about 284 x 183 feet in plan, with the transverse portion being a palm house, dividing the enclosed area into two courts of about 56 x 84 feet. The palm house is a prominent part of the structure, reaching above the rest of the building for a height of 88 feet. The main front has a width of 46 feet and a height of about 50 feet.

The building was designed by Bennett, Parsons & Frost of Chicago under the supervision of David Lynn, architect of the capital. Louis E. Ritter of Chicago was structural engineer for the designers. The general contract was let to George A. Fuller Company of New York City. Steel and structural aluminum were fabricated and erected by the Wheeling Structural Steel Company, Wheeling, West Virginia.

Architectural Aluminum glazing and glazing bars work was executed by the Lord & Burnham Company of Irvington, New York. The cost of the structure including equipment but not land was about $625,000 and is expected to be completed this summer.

Two classes of rolled structural aluminum alloy were specified for channels, which constitute the principal shapes, the sizes range from 3 inch depth with 0.17 in web thickness and a weight of 1.46 pounds per foot to 8 inch depth with 0.27 in thickness and 4.08 pound weight. The specifications provide that aluminum rivets be heated to 940° or 980° F. and driven immediately with heavy pneumatic hammers or preferably by the squeeze method. Aluminum members were assembled by service bolts and the rivets were then driven at random to prevent drawing the parts out of position.

Welding was not used on the structural aluminum but only for aluminum in doors, interior fittings and roof sheathing. No paint or other coating is applied to the aluminum but where aluminum and steel are in contact, both surfaces are given a shop coat of bituministic paint. A field coat of same material is applied to aluminum parts that are embedded in masonry. Steel is finished for use with aluminum paint.

Aluminum sheets and rolled shapes are used for doors and for partition framing while cast aluminum is specified for radiator grills and other interior fittings. Glazing bars or sash bars of aluminum are made by the extrusion process.

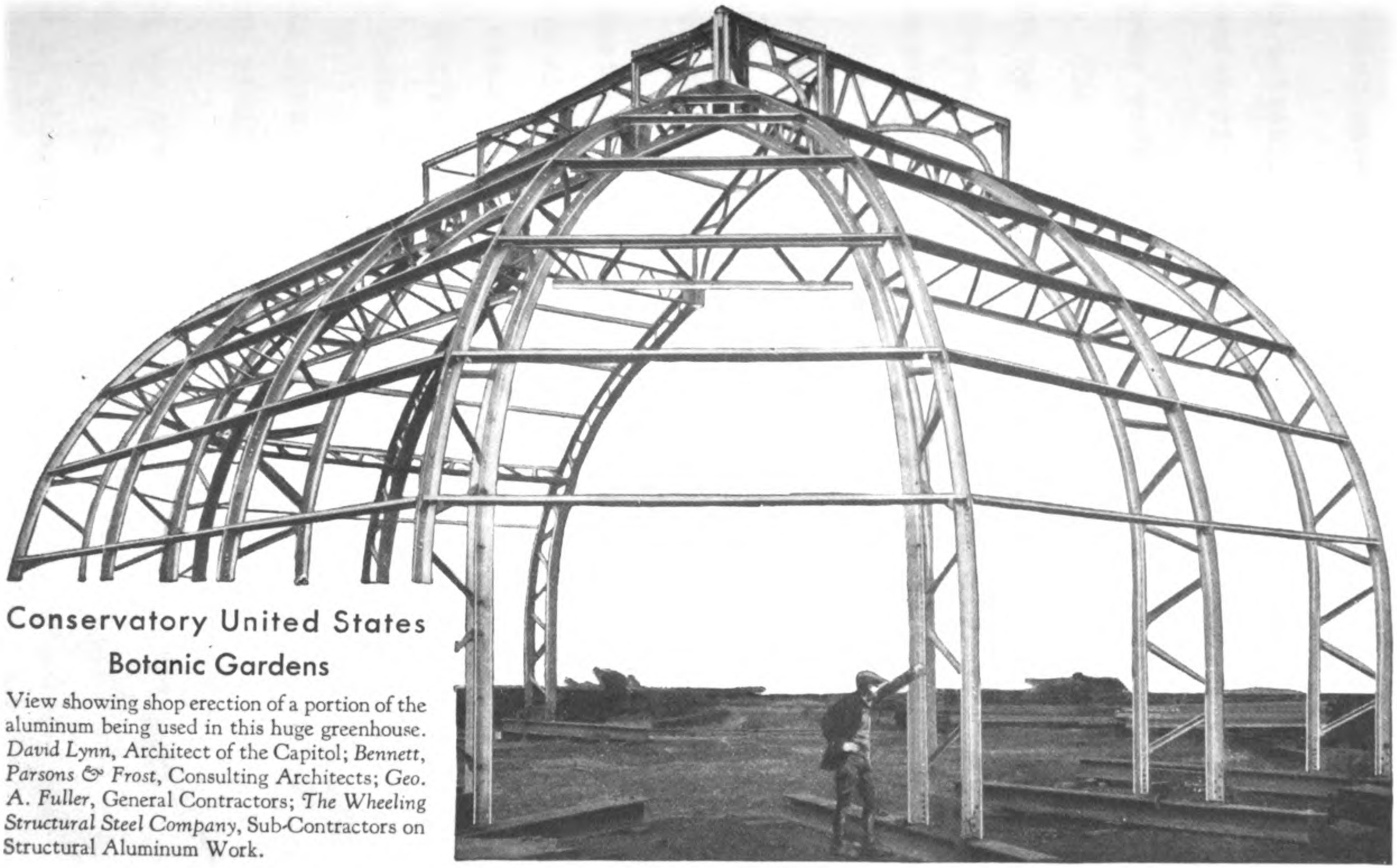
The structure was designed to resist a combined wind and snow load of 25 pounds per square foot normal to the vertical and inclined surfaces. Snow in Washington is infrequent and rarely deep, also it melts quickly. The dead load of aluminum and glass roofing was taken as 4 pounds per square foot.

Fabrication of the aluminum material presented several problems. In most respects the aluminum compared favorably with steel as to its workability but in other ways it was quite different. Due to its light weight it was easy to handle in the shops but ropes were used as a matter of precaution so as not to mar the surfaces which were to be exposed without any covering.

All cuts were made with a saw for the reason that aluminum will not shear with a clean surface. A fine set wood saw or a steel band saw was used for this purpose.

In punching for rivets the metal was found to break before distortion took place around the break making for a clean break.

3/4 inch aluminum rivets were used throughout the structure for fabrication of aluminum parts. Due to the close temperature limit permissible in handling rivets a



Conservatory United States Botanic Gardens

View showing shop erection of a portion of the aluminum being used in this huge greenhouse. *David Lynn*, Architect of the Capitol; *Bennett, Parsons & Frost*, Consulting Architects; *Geo. A. Fuller*, General Contractors; *The Wheeling Structural Steel Company*, Sub-Contractors on Structural Aluminum Work.

A special pyrometer controlled furnace was devised for this purpose which gave excellent results.

No suitable method was found to drive rivets by hand. A compression riveter was used throughout the job.

There were a few special precautions necessary for this job. The aluminum dome was assembled at the fabrication plant before shipment. The freight on the material was considerable. Because of the lightness of the material it was impossible to get within the minimum tonnage for a carload. Considerable expense was gone into in order to insure the material against loss by fire or theft and against damage between the time it left the rolling mills and was erected at the job.

Considerable precaution was necessary in the erection of the aluminum in order to prevent marring. Handling was easy because of its lightness, all methods being used that are utilized in placing steel, except ropes to handle beams in place of chains, in order to prevent marring.

All glass will be set in aluminum sash and held in place with aluminum spring clips.

In the greenhouse part of the building all gutters, sills, ridges, glazing bars and other supporting members of glass are of aluminum formed by the extrusion process and bolted to aluminum purlins.

CHAPTER III

MAGNESIUM AND MAGNESIUM ALLOYS

Methods of Manufacture.

The history of magnesium compounds dates back to 1695 when their oxides were discovered in a mineral spring and used for medicinal purposes. The chemical composition was not completely established until 1808 when Davey showed it to be the oxide of a metal he called magnium, later changed to magnesium.

In 1830 the first coherent substantially pure metal was prepared by Bussy, who fused an-hydrous magnesium chloride with potassium. About thirty-five years later Deville and Caron produced the metal on a manufacturing scale by introducing distillation as a method of separating the magnesium from the impurities present.

The Dow Chemical Company, large producers of magnesium alloys known as Dow metal, has a process for the production of metallic magnesium that is unique from several standpoints. Its basic raw material is a salt brine and not a solid ore. The process consists of the separation of hundreds of tons per day of a mixture of the chemically allied salts, magnesium chloride, calcium chloride, and sodium chloride, in addition to the liberation of bromine. These brine constituents, when separated from the magnesium chloride, become the essential raw materials for other branches of their chemical industry.

The natural brine is pumped from wells 1200 to 1400 feet deep. It contains approximately 14% sodium chloride, 9% calcium chloride, 3% magnesium chloride, 0.15% bromine. After the bromine is removed, the brine is treated with a magnesium hydrate slurry to precipitate the iron and other impurities. The decanted liquor is then evaporated until the sodium chloride has crystallized and is removed on rotary filters. The magnesium and calcium chlorides are separated from each other by fractional crystallization. The magnesium chloride is then dehydrated before being put to an electrolytic decomposition to produce the pure metal. The magnesium metal is lighter than the sludge that forms, so separation is easily accomplished. The average analysis of this magnesium reveals a purity of 99.9 to 99.95%. The minute traces present consist of silicon, iron, aluminum and manganese.

The pure magnesium is alloyed with aluminum, manganese, cadminum and copper to alter their physical and mechanical properties in order to fit them for a wide variety of engineering uses.

Products.

Magnesium alloys have been developed which can be mechanically worked, thereby causing marked improvements in physical properties. Rolling, extrusion, drawing and forging processes are conducted along the same general principals used with other metals,although the details of the different operations have to be regulated to meet certain fundamental

characteristics of this metal.

The magnesium alloys developed and manufactured by the Dow Chemical Company are called Dow metal. There are five standard Dow metal alloys now being used and are designated by the letters "A", "E", "F", "M" and "T", each having characteristics which adapt it for specific purposes. The composition of these alloys is given in the following chart.

ALLOY	% of Elements				
	Magnesium	Aluminum	Manganese	Cadimum	Copper
Dowmetal F	95.7	4.0	0.3		
Dowmetal E	93.7	6.0	0.3		
Dowmetal A	91.8	8.0	0.2		
Dowmetal T	91.8	2.0	0.2	2.0	4.0
Dowmetal M	98.5		1.5		

Dow metal "F" is produced principally for forgings, rolling, and extrusion where maximum ductility is required. For castings requiring good strength without heat treatment Dow metal "E" is usually specified,which is equally as good for mechanically worked parts requiring both strength and ductility. Dow metal "A" is used for high strength heat-treated castings and mechanically worked parts requiring maximum strenghth. For parts requiring maximum thermal properties Dow metal "T" is generally used. Dow metal "M" is specified for places requiring maximum corrosion resistance, also for cast and fabricated parts not subjected to maximum stresses.

The particular use to which the metal is to be put determines the nature and the amount of alloying metals that should be added. Dow metal "M" is a magnesium-manganese alloy in which maximum corrosion resistance has been obtained at a slight sacrifice in properties. Dowmetal "T" is a complex alloy containing magnesium, copper, aluminum, manganese and cadmium with high thermal properties making it valuable for uses in combustion motors and places of excessive heat.

The magnesium-aluminum-manganese alloys are the most widely used at the present time. Alloys containing 6 to 8 percent aluminum and 2 to 4 percent manganese are generally used for castings. Less than 6 percent of aluminum produces an alloy of about the same strength, a little more ductile but with a lower yield point. More than 8 percent aluminum produces an alloy of greater yield point but a lower strength and ductility. By heat treating the casting alloys increase in strength, ductility and toughness.

Fabrication alloys contain 4 to 6 percent aluminum and 0.3 to 0.4 percent manganese. It is possible to successfully work alloys with higher percentages of aluminum, but it is harder because of their lower malleability and close temperature control. The wrought alloys require no heat treatment following fabrication nor do their properties change with aging.

Working is best done to the alloys at 400-800° F. in which temperature range maximum malleability is obtained. A limited amount of cold working is possible on previously worked and recrystallized metal.

Weight.

The weight of magnesium alloys is around 112 pounds per cubic foot. Having a specific gravity of 1.74, it is only two-thirds as heavy as aluminum, one-fourth as heavy as iron, and one-fifth as heavy as brass or copper.

The weight of 24 gauge magnesium sheet metal is 0.189 pounds per square foot.

Structural value.

Alloys for fabrication purposes have tensile strengths as high as 45,000 to 50,000 pounds per square inch with a yield point of 20,000 to 30,000 pounds per square inch. These alloys are difficult to work because of their low malleability and the close temperature control required. The wrought alloys and pure magnesium require no heat treatment following the completion of fabricating operations, as their properties do not change with time due to age-hardening.

The compressive strengths of magnesium alloys in cast form vary from 23,000 to 28,000 pounds per square inch, while in wrought form varies from 55,000 to 65,000 pounds per square inch.

The modulus of elasticity is 6,500,000 pounds per

MECHANICAL PROPERTIES OF MAGNESIUM ALLOYS

	ALLOY and TEMPER	Weight lb.per cu.ft.	TENSION Yield Point lb.per sq.in.	TENSION Ultimate Strength lb. per sq. in.	TENSION Elongation in 2 in. per cent.	COMPRESSION Yield point lb.per sq. in.	COMPRESSION Ultimate Strength lb. per sq. in	Shearing Strength lb. per sq. in.	Endurance lb.per sq. in (Rotating Beam)	Brinell Hardness No (500 kg on 10mm ball
WROUGHT	DOWMETAL M	110	22,000 25,000	38,000 42,000	5-8	38,000 42,000	45,000 50,000	15,000 17,000	9,000 10,000	38-42
WROUGHT	DOWMETAL F	110	26,000 30,000	37,000 41,000	12-16	37,000 41,000	57,000 60,000	17,000 19,000	12,000 13,000	45-50
WROUGHT	DOWMETAL E	110	28,000 32,000	40,000 44,000	10-15	40,000 44,000	58,000 62,000	17,000 19,000	13,000 15,000	50-55
WROUGHT	DOWMETAL A	112	28,000 32,000	42,000 48,000	8-12	42,000 48,000	60,000 65,000	18,000 20,000	14,000 16,000	54-58
WROUGHT	DOWMETAL T	114	27,000 31,000	38,000 42,000	5-9	38,000 42,000	50,000 55,000	17,000 19,000	13,000 14,000	45-50
CAST	DOWMETAL M	110	5,000 7,000	18,000 20,000	3-6	5,000 7,000	28,000 30,000	10,000 12,000	3,000 4,000	38-42
CAST	DOWMETAL E	110	7,000 8,000	28,000 31,000	9-12	7,000 8,000	40,000 42,000	13,000 15,000	8,000 9,000	46-50
CAST	DOWMETAL A	112	8,000 10,000	24,000 27,000	4-7	8,000 10,000	41,000 44,000	14,000 16,000	8,000 10,000	48-52
CAST	DOWMETAL Heat-treated A	112	8,000 10,000	31,000 35,000	9-12	8,000 10,000	42,000 45,000	14,000 16,000	8,000 10,000	48-52
CAST	DOWMETAL T	114	6,000 7,000	22,000 25,000	4-7	6,000 7,000	38,000 40,000	13,000 15,000	6,000 7,000	43-48
CAST	DOWMETAL G	116	10,000 20,000	20,000 38,000	1-8	10,000 20,000	46,000 51,000	12,000 17,000		50-80

square inch for magnesium and its alloys which is 0.65 as much as aluminum and 0.216 as much as steel. Equal rectangular cross sectional areas of magnesium, and steel produce a stiffness in bending in the steel 4.55 times greater than in the magnesium, while two rectangular sections of the same metals of equal weight produce a stiffness 18.1 times greater in the magnesium than in the steel.

Appreciation of the characteristics of magnesium alloys and their suitability for work requiring maximum strength and endurance with a minimum of weight is obtained when their properties are compared with other metals.

COMPARATIVE PROPERTIES OF DOWMETAL - STEEL - ALUMINUM

EQUAL VOLUME RELATIONS

A L L O Y	Relative Weight	Tensile Strength lb. per sq. inch	Elongation %	Fatigue endurance limit in bending in lbs. per sq.in
Mild steel	4.4	60,000	30.0	30,000
Alloy steel	4.4	100,000	20.0	50,000
Aluminum alloy cast.	1.6	33,000	8.0	
Duralumin.	1.6	60,000	20.0	15,000
Dowmetal cast.	1.0	33,000	10.0	9,000
Dowmetal wrought	1.0	42,000	12.0	14,000

EQUAL WEIGHT RELATIONS

A L L O Y	Relative Weight	Tensile Strength lb. per sq. inch	Fatigue endurance limit in bending in lbs. per sq. in.
Mild steel	4.4	60,000	30,000
Alloy steel	4.4	100,000	50,000
Aluminum alloy cast.	4.4	91,000	
Duralumin.	4.4	177,000	70,000
Dowmetal cast.	4.4	145,000	80,000
Dowmetal wrought.	4.4	185,000	125,000

Heat treated magnesium alloy castings are seen to be equal in strength volume to volume of heat treated aluminum alloy castings. It may be seen that wrought magnesium alloy has approximately the same fatigue endurance as duraluminum but somewhat lower tensile properties. When the cross sectional area of magnesium and aluminum alloys are increased until they weigh the same as steel, the magnesium alloys show their superiority to both aluminum and steel. In tensile strength the wrought metals compare as follows: aluminum alloy is 1.72 times stronger than steel while magnesium alloy is 1.85 times greater in strength. In the fatigue endurance limit in bending magnesium alloy is 2.5 times stronger as compared with 1.6 times stronger for aluminum alloy.

The coefficient of thermal expansion is 0.000029 inches per degree F. which is less than aluminum but greater than steel. As stated before, temperature stresses are not necessarily severe, therefore, it is not such a large factor as it first seems.

Durability.

Magnesium is as permanent and corrosion-resistant as the other common metals used in engineering when subjected to atmospheric exposure. The bright metallic surface is soon dulled by the oxide film that forms on the surface but does not flake off when exposed for long periods. Where corrosion occurs in long-time exposure tests there has been found that a slight loss occurs in the strength equivalent to the loss in area but no loss in ductility or strength can be attributed to intercrystalline corrosion.

Research has been carried on during the last few years to improve the corrosion resistance of magnesium. Manganese has been added in alloying the metal and has greatly improved the corrosive resistance of the alloys. A low percentage of manganese (between 0.3 to 0.5 percent) has been found to be very effective.

When the metal is placed where exposed under very severe conditions, it has been found a good practice to protect the surface with a lacquer, paint, or enamel that is resistant to the particular corrodent.

<u>Insulation. - Heat.</u>

The thermal conductivity of pure magnesium is 0.38 C.G.S. and when alloyed this is reduced to a figure between 0.18 and 0.30 C.G.S. This is a lower thermal conductivity of heat than aluminum which is between 0.27 to 0.53 C.G.S. Magnesium is used as other metals in the insulation field that is by using it in sheet form for spandrels and wall surfaces with insulation between the sheets. The insulating material does more than the metal in stopping the penetration of heat and cold so therefore the insulating value is vested in the insulating material while the dead weight of the wall is reduced by the use of metal as a protective coat.

Insulation - Sound.

The penetration of sound is reduced by the use of the sheet magnesium for wall surface, but the sound waves are unabsorbed by the smooth surface, thus increasing reverberation. The best use of sheet metal for walls is confined to walls of small rooms such as offices.

Insulation - Fire.

In case of fire, again the value against penetration is vested in the insulation that is placed in the wall, and not in the wall covering, which is of particular interest at the present time. This insulating may be made of a lightweight material so the dead weight for walls is not necessarily as large as one first expects.

Insulation - Dampness.

The power of penetration resistance of magnesium metals is found in the joints. Magnesium alloys can be readily welded with an oxyacetylene torch. The filler rod should be of the same approximate composition as the material being welded.

Workability.

Magnesium and its alloys can be fabricated in any of the following methods: flanging, rolling, extrusion, drawing, forging, oxyacetylene or electric spot welding and riveting. Magnesium is the easiest of all metals to machine.

The speed of turning and the depth of cut can both be increased. In general, the same procedure is followed in working magnesium alloys as is followed in the processes of working aluminum.

Uses.

The use of magnesium alloys has confined itself mainly to the airplane industry, mostly because of the extreme necessity of lightweight material with maximum strength and durability without regard to cost. In this industry, it means an extra pound of pay load can be added for each pound of dead weight reduced.

At the present time the price is still extremely high to be used as a structural material in the fabrication of structures, but with the increasing consumption and decreasing price, coupled with the fact that magnesium is the eighth most abundant element of the earth's crust or the sixth most abundant metal, the possibility of the use of magnesium alloys in competition with heavier metals seems apparent. The possibilities in the practical application of magnesium alloys are just becoming apparent. In 1915 the consumption of magnesium was 87,500 pounds at an average price of five dollars per pound in the ingot, while in 1929 the consumption had jumped to 908,351 pounds and the price had dropped to fifty-seven cents per pound in ingot form. At present the alloys are available in most forms required by the designing engineer. Foundry technic, fabrication methods, and alloy compositions have been so perfected that construction parts made from magnesium alloys are recognized as having the properties and stability demanded in modern ultra lightweight metal. Larger production and improvements in plant operation will make the magnesium alloys able to compete with heavier metals.

CHAPTER IV.

LIGHTWEIGHT STEEL PRODUCTS

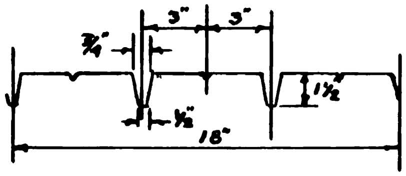
There are two methods of reducing the dead weight in structures; namely, by reducing the density of the material or by reducing the amount of material by using only enough material to supply the required strength. The two previous chapters delt with the first method of reduction, while good examples of the latter are the different building units made of concrete, etc. where the center is usually hollow with a thin shell around these voids. Recently more use has been made of this method in reducing the dead weight by using 18 to 22 gauge metal and pressing these to conform to different shapes in order to put strength into the shapes. Among these products are steel roof decks and pressed steel joists.

Method of Manufacture.

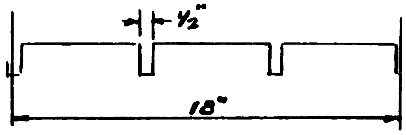
The particular plate is formed on modern cold forming machines. These machines are of special design and are so constructed that the steel is gradually folded and shaped through a series of rolling dies - a flat sheet being fed into one end and the finished product discharged from the other end ready for painting. By this method internal stresses in the plates are avoided and cracks and ruptures are prevented.

Products.

The United States Gypsum Company has produced a modern steel roof deck of special copper alloy steel, containing not less than .20% copper, which combines unusual strength with light weight and ease of erection. Extra strength and rigidity in the deck plates are provided by intermediate stiffening beads, three-eighths inch deep between reinforcing ribs that are rolled into the plate on six inch centers and are one and one-half inches deep, with a one-half inch base. In cross section these sections are uniform but at one end they are narrowed to permit nesting of top sheet with bottom sheet without distorting or fanning the deck plate.



Cross Section of
Center



Cross Section of
Over-lapping End

There are numerous kinds of lightweight steel joists that tend to reduce the dead weight of floors. Among these are plate girder joists, manufactured by the Truscon Steel Company of Youngstown, Ohio, and are made by welding four angles to a strip of steel 6 or 8 inches deep to make a section similar to an "I" beam. The use of these members is nearly obsolete. The Jones and Laughlin Company of Pittsburgh, rolls a very light "I" beam known as Junior "I" beams, but these sections have been in very little demand up to the present time. The Berger Manufacturing Company, the Truscon Steel Company and the National Pressed Steel Company manufactured lightweight pressed steel joists some years ago. Since, all of these companies have discontinued making these joists because they are no longer an article of commerce.

Pressed steel joists have practically been replaced by the open web steel joists which is almost the only article used for such purposes. Open web joists are manufactured by cutting members, by shearing and then bending the rods in a semi-automatic bending machine and welding with either an arc welding torch or with an electric resistance welder. The Kalman Company makes an open web joist by slotting a hot 4 inch "I" beam and expanding while still hot.

Properties of U. S. G. Steel Roof Deck.

The steel roof decks are made in three gauges, No. 22 gauge deck with weight of 2.0 pounds per square foot; No. 20 gauge deck with weight 2.4 pounds per square foot and No. 18 gauge deck with weight of 3.2 pounds per square foot.

The following data was obtained by actual tests on U. S. G. Steel Roof Deck Plates at the Armour Institute of Technology, Chicago, Illinois. The loads given are live loads. An allowance of five pounds per square foot has been made for the dead load which consists of deck plates, insulation and the roofing materials.

ALLOWABLE LIVE LOADS IN POUNDS PER SQUARE FOOT

Factor of Safety of Four

Gauge	Purlin Spacing 4'0"	4'6"	5'0"	5'6"	6'0"	6'6"	7'0"	7'6"	8'0"
22	83	66	53	44					
20			81	67	56	48	41		
18*					71	60	52	45	39

*Factor of safety 3.5

Deflection in Thousandths of an Inch.

Span	Gauge	Live Loads in Pounds Per Square Foot 25 lbs.	30 lbs.	35 lbs.	40 lbs.	45 lbs.	50 lbs.
4'0"	22	.041"	.048"	.057"	.066"	.074"	.084"
4'6"	22	.066"	.078"	.092"	.106"	.120"	.135"
5'0"	22	.101"	.120"	.141"	.162"	.183"	.207"
5'6"	22	.148"	.176"	.206"	.237"	.268"	-----
5'0"	20	.075"	.090"	.107"	.123"	.140"	.157"
5'6"	20	.124"	.141"	.173"	.197"	.223"	.249"
6'0"	20	.148"	.179"	.211"	.242"	.274"	.305"
6'6"	20	.196"	.234"	.276"	.318"	.361"	.403"
7'0"	20	.272"	.329"	.384"	.442"	-----	-----
6'0"	18	.110"	.132"	.153"	.175"	.196"	.217"
6'6"	18	.148"	.178"	.206"	.236"	.264"	.293"
7'0"	18	.190"	.229"	.265"	.303"	.344"	.381"
7'6"	18	.249"	.300"	.348"	.397"	.451"	-----
8'0"	18	.325"	.391"	.453"	.517"	-----	-----

All U.S.G. steel roof deck plates are either galvanized or have one dip coat of semi-gloss light grey paint. This paint gives a highly satisfactory appearance and has maximum light diffusion with a minimum amount of glare. It furnishes a reliable protective coating against corrosion of the steel. It also provides an excellent base for a field coat of paint if this is desired.

The application of insulation over steel roof decks

is recommended. The insulation helps to keep the interior of the building cool in the summer and warm in the winter. Also insulation properly applied tends to eliminate condensation and the resultant damages to the deck.

The following table gives the heat transmission expressed in B.T.U.'s per hour per square foot per degree difference in temperature. Five ply roofing is included.

U.S.G. Steel Deck - No insulation	0.781 B.T.U.'s
U.S.G. Steel Deck - ½" insulation	0.358 B.T.U.'s
U.S.G. Steel Deck - 1" insulation	0.232 B.T.U.'s
U.S.G. Steel Deck -1½" insulation	0.172 B.T.U.'s

This shows that the greatest part of the insulation of the roof is in the insulating material and not the roof deck.

Rapid erection is a feature of the U.S.G. Deck. The plates are made eighteen inches wide and are of convenient size for easy handling. The reinforcing ribs nest perfectly at end laps with a minimum amount of effort. Four types of non-piercing attachment clips are furnished for securing the deck plates in place. These clips further facilitate speedy erection, and, in addition they possess more than adequate holding power to satisfy cyclone insurance requirements.

Saddles can be made from the deck plates and are easily fitted in place. Ridge, valley and backing plates and other accessories can be furnished as required.

The U. S. G. steel roof deck plates are manufactured in the United States Gypsum Steel Products Plant.

Properties of Steel Joists.

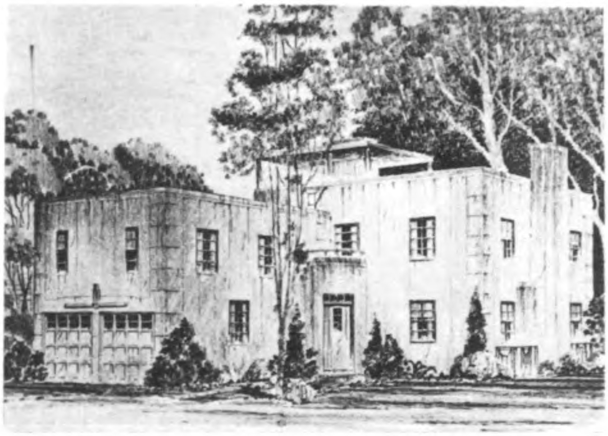
The weights of open web joists vary greatly with the different makes for the reason that no two companies' joists weigh the same. It is quite easy to estimate the weight of any joist by taking the weight of the chord sections and web members, which are usually bars of uniform cross-section. There is about ten percent variation between the lightest and heaviest sections.

The steel joists are made in standard depths of 8", 10", 12", 14" and 16" and in lengths to accommodate all spans up to 32'0". The 8" depth joist has an allowable resisting moment of 29,500 in pounds and a maximum end reaction of 1600 pounds while the largest joist, the 16" size, allows a resisting moment of 281,000 in pounds and a maximum end reaction of 3600 pounds.

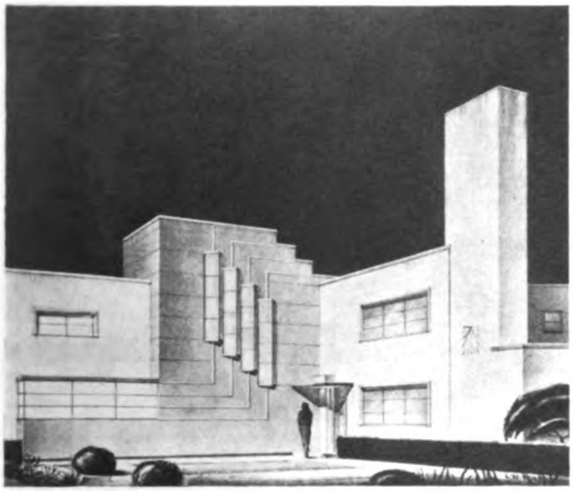
As to durability, the steel joists are painted with an asphaltic paint before leaving the shop, and, if used in dry locations, they are entirely permanent. When used in damp places such as unexcavated places and places where moisture is excessive, they are subjected to excessive corrosion unless highly protected with paint.

As to the use of steel joists, they are used very largely in buildings, school houses, churches, apartment houses and other buildings of light occupancy and to a lesser

FIRST PORCELAIN-ENAMEL HOUSE, sponsored by the Ferro Enamel Corporation is under construction in Cleveland. Exterior porcelain-enamel sheets are ½" deep, panels varying in size up to about 30" square and "sandwiching" a fiber insulating board held by a waterproof glue. Special steel studs are fabricated. Horizontal joints have a slight ship-lap. The total wall thickness is about 4 inches. Charles Bacon Rowley and Associates are the architects and engineers, with Meade Ashley Spencer as associate.



EXPERIMENTAL FRAMELESS STEEL HOUSE erected in a Cleveland suburb by the Insulated Steel Floor and Wall Company. Stamped steel sheets are used for the construction of floors and walls. Overlapping joints are welded and a filling of mineral wool is used for insulation between the steel sheets. This system of construction is said to have unusual heat and sound insulating qualities, and a flexibility which makes it adaptable to almost any type of building. The experimental work is under the direction of Mills G. Clark of the American Rolling Mill Company.



GARDEN FACADE OF REID HOUSE at Rome, N. Y., by Pierre Blouke, Chicago architect. This house uses the Dovell system of steel framing, for the floors are supported continuously on steel-plate spandrels; cantilevers, which are units with the columns, allow shorter spans. Curtain walls used in conjunction with the steel frame consist of copper-covered hollow gypsum blocks in large units.

Shannon

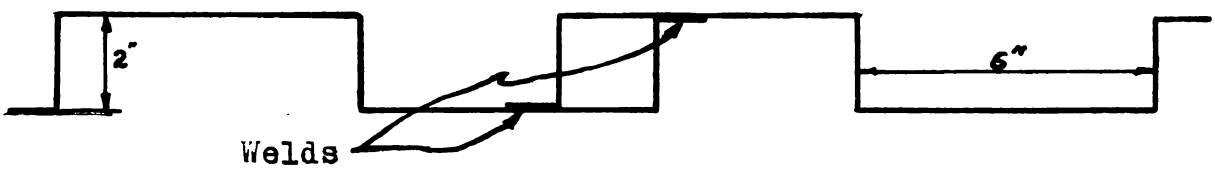
MODEL OF FARMHOUSE OF LOW COST with use of available materials produced by industry. Light steel tubes support a stamped steel floor system. Exterior walls and partitions are of 1" insulating board faced with enameled sheet steel. The house was designed by A. Lawrence Kocher and Albert Frey for the President's Conference on Home Building and Home Ownership, 1931.

extent in stores and factories unless a light live load is anticipated in the building.

An experimental house is now being constructed at Solon, Ohio which will find a method of home construction that will provide heat and sound insulation at no greater cost than the prevailing frame construction. The home is planned by Mills G. Clark of the Insulated Steel, Inc. of Cleveland. The American Rolling Mill Company and Westinghouse are also interested in the project.

The house is to be built entirely of sheet metal insulated and protected on both sides. For the walls, box-like corrugations are pressed in flat sheets forming sections one, two, and three feet wide, and of the length necessary. These units are welded together in the shop, story high and room wide, and the walls for each room hauled to the site in one piece, no structural steel work being necessary.

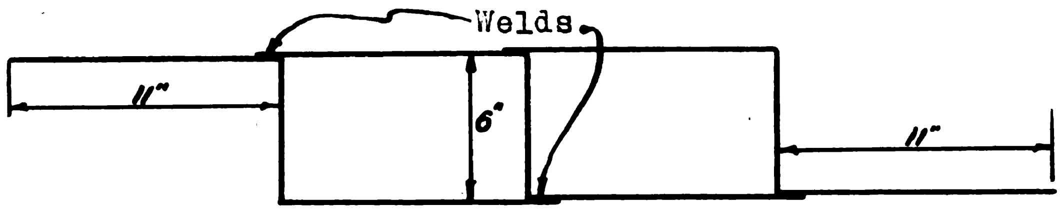
Lap becomes hollow column for
strengthening construction.



18 gauge wall sheets in 12", 24" and 36" widths-
story height length.

For insulation and sound-proofing, the box-like corrugations are filled with rock wool; then a layer of insulation board will be fastened to the protruding sheet metal with a structural adhesive, both inside and out. Exposed to the weather is a layer of asbestos tiles or aluminum, also fastened with structural adhesive. The interior side of the wall may be finished with wallpaper or any other decorative finish. Although the completed wall will not exceed three inches in thickness, it will possess unusual insulating qualities.

The floors and roof will be of 16 gauge sheet metal, formed as shown in details and welded on the job to form a series of strong metal boxes 6 inches high by 10 inches wide.



16 Gauge floor sheets, 16 ft. to 24 ft. long.

It is estimated that a two-story house of ordinary size can be completed and ready for occupancy within thirty days.

Electric welding will be used quite extensively to assemble the units. The wall sections room wide and story high will be laid out, welded, insulated and finished on both sides in the shop and erected on the job as a unit. The floor sections are assembled and welded on the job.

CHAPTER V.

CINDER CONCRETE

Methods of Manufacture.

Cinder concrete is one of the lighter materials, made so by the mixture of light ingredients. Also small air spaces are trapped in the cinders making a combination of the two lightweight qualities, light material and air spaces. Carefully selected or specially purified cinders, crushed to the proper fineness are used in place of standard aggregates. Portland cement is used as a binder. When producing blocks, the cinder concrete is properly mixed and placed in molds and molded under heavy pressure. Cinder blocks, brick and tile are made under the Straub and Bo patent in authorized plants throughout the country.

Products.

Cinder concrete is produced for use in many places where standard concrete is used. Cinder concrete is quite porous, therefore it is not generally used for finished floors or places where a smooth finish is required.

Standard building units are produced in the blocks, that is, units having wall area of 8" x 16" and standard thickness of 3", 4", 6", 8", 10" and 12". Also reinforced lintels, bricks, half blocks, quarter blocks, jamb blocks, sash blocks, header blocks, corner blocks and solid slabs are furnished for use in connection with standard units which are of great importance in simplifying erection.

Blocks are also produced with a small amount of colored aggregate mixed in with the cinders to produce a speckled effect in the blocks used for finished blocks in both exterior and interior walls.

In order to compete with tile manufacturers a block has been produced whereby tiles are cemented to cinder blocks thereby creating a wall with a tile surface, yet without materially reducing the lightness of the blocks.

Weight.

Weight Per Cubic Foot.

54 Pounds	Hollow Cinder Unit
54 Pounds	Hollow Clay Tile
80 Pounds	Solid Cinder Unit
84.5 Pounds	Hollow Concrete Unit
125 Pounds	Clay Brick
140 Pounds	Solid Concrete

A standard 8" x 8" x 16" cinder block weighs 32 to 34 pounds as compared to approximately 50 pounds for a sand concrete block or equals a wall of 12 bricks, weighing close to 60 pounds.

Lighter cinder concrete units are made for non-bearing partitions and curtain walls.

100 square feet of 8" wall will require

3600 lbs. of cinder blocks

5500 lbs. of sand concrete blocks, or 25% more

6500 lbs. of clay brick, or 80% more.

Structural Value.

Cinder concrete meets the requirements of the most rigid building codes. At the factories manufacturing the cinder blocks, the units are subjected to tests at regular intervals and the manufacturing license requires a strength at the age of 28 days of not less than 700 pounds per square inch of gross area. Generally this requirement is greatly exceeded and units have been constructed to stand a pressure greater than 2000 pounds per square inch.

The strength of the masonry unit should always be considered in its relation to the strength of the wall. The essential factors in imparting this unit strength to the wall itself are the quality of the mortar and its adhesion to the unit. With cinder block the mortar bond develops its full strength because the limited suction of the unit prevents the drying out of the mortar bed while the rough texture of the block gives the joint a perfect key.

The Department of Civil Engineering at Columbia University made the following report on compression test tests made in their laboratories on cinder block piers.

Height of Pier	Size of Unit	Compressive strength of pier.	Compressive strength of unit.	Ratio.
54.1"	8"x8"x16"	704#/sq. in.	927#/sq. in.	.758
53.8"	8"x8"x16"	649#/sq. in.	927#/sq. in.	.700
54.0"	8"x12"x16"	719#/sq. in.	1315#/sq. in.	.547

Durability.

The cellular structure of cinder concrete makes for its toughness which reduces cracks or spalling to a minimum.

When water is placed in contact with any material and then subjected to successive freezing and thawing, invariably cracks are produced in the materials. Cinder concrete has been able to withstand such treatment by virtue of the fact that the cellular structure permits for the expansion of the water without forcing the cement to break its bond holding the particles together.

In regard to the lasting qualities of concrete it may be said, the factor which makes the bond is the cement, the factor which deteriorates concrete is any one of three reasons; first, not sufficient cement; second, impurities mixed into concrete so that proper bond is not able to be effected; third, sound aggregates not used. It is plainly seen that the only factor of these three in which the cinder concrete might differ from other concrete is the third. That is the soundness of the aggregates. Tests have proven that cinder concrete has been able to produce strength far in excess to that required by building codes. Therefore, the cinder aggregate may be said to be sound. With these three requirements satisfied, cinder concrete should act as other concrete in regard to strength as the age increases. This has been proven by tests of concrete at different stages of aging. Cinder concrete acted the same as concrete of standard aggregate in this respect for increasing age increases strength.

Insulation. - Heat and Cold.

The cellular, cork-like structure of cinder concrete creates an insulation that forms an integral part of the structure.

The coefficient of heat conductivity for a typical 8"x8"x16" cinder block as determined by E. L. Conwell & Company of Philadelphia, Pennsylvania is 1.77. The large dead air space in the cinder block makes for a lower coefficient than in the solid concrete.

The nailability of cinder concrete makes it easy to add cork insulation directly to the surface without the addition of nailing strips. This method is often used in ice houses, cold storage houses, dry kilns or other places where it is necessary to maintain constant temperatures.

Insulation - Sound.

The feature that makes a wall a good sound insulator is the property to absorb the sounds and not let tham reverberate back into the room or pass through the wall into the next room.

The rough surface texture of cinder concrete used in walls tends to absorb sound waves in place of reflecting them back into the room, also the cellular structure of the cinders makes the passing of the sound through the wall difficult, thereby making cinder concrete a good insulator against sound.

Insulation - Dampness.

There are two causes for the dampness or sweating that appears on the interior of some walls. The first is the condensation of moisture on a fast cooling wall. The second is the capillary action that draws moisture through the wall. Cinder concrete eliminates condensation because the cellular structure makes the temperature of the concrete slow in changing.

Capillary action is extremely slight in cinder concrete. This has been tested by placing a unit in a pan of water, keeping the water to the original level and noting the height to which the moisture rises. Repeated tests have shown the capillary attraction in cinder concrete after being tested for a period of one month to be not more than one or two inches. After performing a comparative test of this nature using stone concrete and cinder concrete back up units, the owners of the 23 story tower built by the Lincoln National Bank and Trust Company at Fort Wayne, Indiana decided to use the cinder concrete units even at a higher price per unit, figuring the extra insulating properties would offset the original cost.

Insulation - Fire.

The term "fire resistant" embraces several factors almost of equal importance. Resistance to flame is vital. Prevention of heat transmission and cohesive character of a wall that neither bulges nor cracks is equally essential, and after a fire the salvage value is of primary importance.

At the Underwriter's Laboratories, cinder block walls were subjected to a fire test, fire and water test and impact test. In these fire tests 8 inch cinder block panels 10' 1" wide and 11' 3" high, formed the front wall of a gas furnace. The temperature of this furnace reached 1300° F. in ten minutes and more than 1900° F. in three hours and fifteen minutes, When the unexposed face of the cinder blocks registered an average of 300° F. The blocks showed no spalling, cracking or structural damage, and the maximum deflection of the wall, due to heat expansion, was less than ½ inch.

At Tenafly, New Jersey, a hollow five inch wall of cinder blocks resisted a wind-driven fire for three and one-half hours. During this time 500 gallons of water per minute was directed against the heated wall surface, creating an unusual condition of expansion and contraction. After the fire there were no evidences whatever of heat penetration. The three-story structure was undeflected and uncracked. The cinder blocks were fit for use again.

The impact test consists of submitting the wall to the impact of a heavy steel and concrete member following the exposure to fire and water, two blows being given the wall to determine if the fire and water weakened the stability of the wall in any way.

Workability.

Nails can easily be driven into cinder concrete, and will hold firmly and never rust. Actual tests have shown that a 20 d nail in a 2 x 4 yellow pine driven to a depth of 1½ inches requires a force of 260 pounds to draw the nail. A 20 d nail in cinder concrete driven to the same depth required an average of 250 pounds to draw the nail. An old nail having been embedded 1½ inches for five years required 650 pounds to draw. The nail had not rusted in the cinder concrete although it had rusted where not embedded.

All nailing strips, and plugs can be eliminated. Grounds, base boards and trim may be fastened direct to the wall.

No difficulty is experienced in cutting or channeling the material, due to the cellular structure of the cinder concrete. Breakage of cinder concrete building units is small and to further facilitate construction, these units are supplied in halves, quarters, and other fractions so that cutting is reduced to a minimum.

The surface texture of cinder concrete affords an ideal base for plaster and stucco. These materials are applied direct to the wall and dovetailed into the small irregularities of the surface, giving a strong key. The rough surface makes possible the use of cinder block laid in broken ashlar or random designs and then white-washed, creating a variety of attractive effects.

Uses.

A good summation of the uses of cinder concrete can be found by the following excerpts from a recent article in "Concrete" by J. Arthur Garrod, Superintendent of Construction of Boston, Massachusetts, commenting on an investigation of the use of cinder concrete in New York City buildings.

> "The cinder concrete floor arch has been used with good results in recent buildings constructed in New York City. The system probably will hold its own against other methods as long as the materials remain plentiful.
>
> "The resulting floors appear to be adequate and adapted admirably to the placing of inserts and the passing of pipes. The floors can be cut in two without undue expense and can be patched after alterations with reasonable certainty of success. They receive plaster admirably and seem to afford sufficient bond to insure permanent adhesion.

"The top surface of cinder concrete can become an excellent base for cement finish, or a base for linoleum in offices and terrazzo in corridors."

CHAPTER VI.

HAYDITE AGGREGATE

Description of Manufacture.

As the lumps of clay or shale roll down the kiln they are preheated at a temperature of approximately 800° F., which vitrifies a thin layer on the outside of each particle thus confining the combustion gases resulting from subsequent burning of the inner portion of the raw material. When the preheated particles reach the burning zone they are subjected to intense heat from the impinging flame of the second fire nozzle, which brings them to incipient fusion, approximately 2000° F. At this point the vitrified outer layer is softened and the sudden rise in temperature causes the confined gases to expand, puffing the lumps out to $2\frac{1}{2}$ times their original size, and the expanded material partially fuses forming porous clinkers composed of minute cells each surrounded by a wall of vitrified clay. The clinker is then dropped from the kiln and allowed to cool.

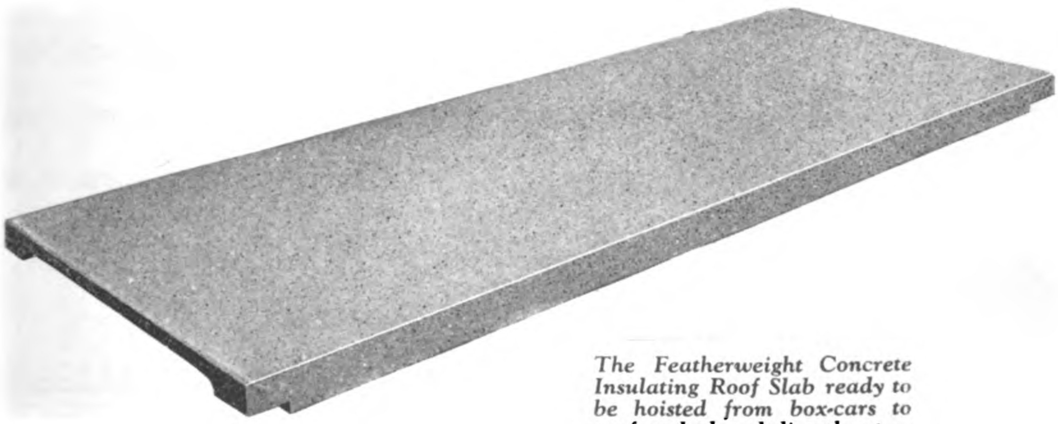
Units made.

Inasmuch as haydite is an aggregate rather than a manufactured unit, it may be used as any other aggregate in the processes that other aggregates are used. One of the largest uses is in the manufacture of precast roofing slabs.

Weight.

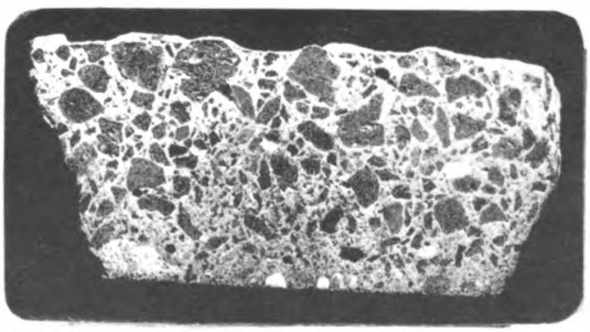
Concrete using haydite weighs 100 pounds per cubic

Micro-photograph of Haydite clinker showing its unique cellular structure. It is the presence of these countless trapped air cells, each with walls of thoroughly vitrified shale, that give Featherweight Concrete Insulating Roof Slabs their great strength, light weight and insulating value.



The Featherweight Concrete Insulating Roof Slab ready to be hoisted from box-cars to roof and placed directly upon the steel purlins. Erection is performed by our own skilled forces, anywhere throughout the entire country.

Photograph of cross section of Haydite concrete slightly enlarged, showing the dense, impervious structure of the concrete and the cellular nature of the Haydite.



foot as compared with 140 pounds per cubic foot for concrete made with standard aggregates. Used in concrete masonry an 8"x8"x16" unit meeting standard specifications, weighs 26 pounds as compared with 47 pounds, the weight of a standard concrete unit of the same size.

Strength.

Haydite concrete has the strength of standard concrete and may be designed for any given strength by standard methods of water-cement control.

An analysis of the compression tests on 3" x 6" cylinders of haydite concrete consisting of one part of cement to approximately three and one-half parts of haydite gave compressive strengths of -

2350 lbs. per square inch at 10 days
3850 lbs. per square inch at 28 days

Durability.

The University of Wisconsin submitted feather-weight haydite building units to 100 alternate freezing and thawings. The average temperature of freezing chamber being 21 degrees F. After freezing solid, the specimens were placed in a tank of water with a temperature of 140 degrees F. for one hour thawing period. This constituted one reversal. This procedure was repeated 100 times. Tests showed that after this procedure of 100 freezing reversals that the average strength was higher than the average strength of similar specimens tested at the end of 28 days. The average strength for 28 days being 801 pounds per square inch, while the average strength after the freezing test was 950 pounds per square inch. This shows an increase of 149 pounds per square inch. Although this is not as great an increase in strength as though the concrete were cured under natural conditions, it shows that such severe conditions do not weaken the concrete.

The Robert W. Hunt Company, engineers, made a complete analysis of a sample of haydite and found the following substances, -

<u>Ignition Test</u>

Loss on Ignition	None
Silica	59.00%
Iron Oxide	10.43%
Aluminum Oxide	26.17%
Calcium Oxide	1.08%
Magnesium Oxide	1.23%
Total Sulphyr Calculated to Sulphuric Anhidride	0.55%

This totals 98.46% of original sample, the balance being probably alkalies.

<u>Water Soluble Analysis</u>

Total Solids	0.24%
Sulphuric Anhidride	0.088%
Chlorine	0.007%
Reaction	Alkaline

The indications are that this material would not cause corrosion when used as aggregate for concrete in connection with reinforced steel.

<u>Insulation.- Heat and Cold.</u>

Haydite, being composed of pockets of dead air entrapped by walls that are as hard as vitrified brick, makes it a very good insulator of heat or cold.

The coefficient of heat conductivity for a 12" x 12" slab of ordinary haydite concrete one inch thick, with a density of 73.00 is 1.62 British Thermal Units per hour when the difference in temperature is 1 degree Fahrenheit.

Insulation - Sound.

The Riverbank Laboratories of Geneva, Illinois made a series of tests of the transmission of sound by partitions of different materials.

These tests were conducted by what is known as the Reverberation Method which is performed as follows: Sound of a known initial intensity is produced in a highly reverberant room, whose acoustical constants are known from an initial calibration. From the measurement of the times required for this sound to reach the threshold of audibility, first in the sound chamber, and then in the test chamber on the opposite side of the test wall, the relative intensities of the direct and transmitted sound are computed. The logrithm of the ratio of these intensities is taken as a measure of the sound insulating merits of the test partition. Tests of this sort were made using 17 different tones covering the ordinary range of pitch. The average value of these quantities is taken as a single figure which expresses the sound insulating properties of the walls. Multiplying this average value by 10 gives the difference in loudness of sound on opposite sides of the test partition in sensation units. A difference of one sensation unit corresponds to a change in intensity which is just as perceptible as difference in loudness as judged by the ear.

The results of the tests are as follows:

	Wt. per sq. ft.	Reduction
3" Solid Gypsum Tile, Plastered	25.4	32.8
4" Clay Tile, Plastered	28.0	34.0
2½" Gypsum Plaster on Metal Lath	23.2	32.4
4½" Gypsum Plaster on Metal Lath	41.8	38.2
Wood Stud, wood lath, plastered	18.0	28.0
4" Haydite Tile, Plastered	23.2	38.0

Conversational speech can be faintly heard but not understood and the sound of a phonograph is almost completely extinguished through a haydite partition.

Insulation - Dampness.

The absorption of haydite concrete is slight and capillarity action of moisture is lacking. This is due to the porous or cellular nature of haydite. Condensation is eliminated because the temperature of the wall is slow in changing, thereby leaving the moisture suspended in the air of the room without reaching the saturation point.

Many buildings have been constructed with the plaster applied direct to the haydite concrete building unit without lathing and such construction does not show dampness, cracking or discoloration of the plaster.

Insulation - Fire.

Exposure to the fire endurance and fire stream tests indicates no abnormal heat conductivity, expansion, contraction, cracking, spalling, fusion, erosion or other disintegration of the units due to their haydite content.

Workability.

Nails are readily driven into the concrete, saving nailing plugs and strips. Nails will not rust or come loose. The aggregate is completely inert. Haydite is a preservative of metals, there being no danger of corrosion of steel, nails, conduits, pipes, metal lath, metal wall ties, and other metals coming in contact with haydite concrete.

Cutting or channeling is done easily with an ordinary mason's hammer.

The lightness makes handling of the concrete very easy, both in the form of building units, precast slabs or as a mix to be placed in forms.

Availability.

The available sizes of haydite for uses in manufacture and their general uses are as follows:

Haydite "A"	00" to 3/16"	Used as fine aggregate in concrete products and general construction.

Haydite "B"	3/16" to 1/2"	Used as coarse aggregate in precast concrete products.
Haydite "C"	3/16" to 3/4"	Used as coarse aggregate in heavy precast products and in reinforced concrete in all its branches.

Uses.

Owing to its extreme lightness haydite is an ideal aggregate for such precast concrete products as building units, roofing tile, laundry trays, burial vaults, conduit tile, water and sewer pipe, drain tile, railroad ties, lighting standards, telegraph and telephone poles, and precast roof slabs.

In reinforced concrete structures, the saving in steel area by reduction of dead load which is about 35% to 40%, coupled with the fact that haydite makes a fire-resisting, non-corrosive concrete, makes it a very good aggregate for general building construction, fireproofing steel buildings, reinforced floor slabs, floor fills, water and oil tanks, stacks, bridges and viaducts.

Example of Uses.

Precast feather-weight haydite floor slabs (300,000 sq. ft.) were used in the Ford Museum at Dearborn, Michigan, while feather-weight haydite roof slabs (200,000 sq. ft.) were used in such buildings as the Detroit Municipal Airport. The A. O. Smith Corporation Research Laboratory used precast roof slabs of haydite aggregate, being but one of the many modern features that has brought this building to public attention.

The Public Service Companies of Northern Indiana and Northern Illinois used precast wall slabs of haydite concrete in their generating plants at Michigan City, Indiana and Waukegan, Illinois.

Numerous homes have used haydite building blocks for walls, using stucco directly applied for outside covering or painting with whitewash or concrete paint while the inside walls are covered directly with plaster.

CHAPTER VII

AEROCRETE

Methods of Manufacture.

Aerocrete is made by the addition of aluminum powder to Portland cement and aggregate. When the water is added to this mixture the hydrogen and the oxygen of the water is freed causing expansion within the concrete, Upon hardening, the volume of concrete becomes much larger. In this condition the material can be sawed, planed or nails can be driven into it very easily.

The texture of the material resembles that of cork, it being full of small and evenly distributed cavities, which make up 70% of its volume. Each one of these cavities is a closed compartment surrounded by thin walls, and this is the reason the material has such good insulating qualities, though the heat insulating properties of expanded concrete are more than three times greater than those of brick- and seven times greater than those of ordinary concrete.

The material can be made in blocks or it can be cast in place. Tests have been made to ascertain the amount of adhesion between expanded concrete and steel reinforcing. It has been found that the bond is proportionate to that which takes place between steel and solid concrete.

It is possible to produce a concrete so light that a cubic foot weighs only 20 pounds. The strength however decreases rapidly when the material is made very light. Therefore, for building purposes, a material weighing 42 pounds per cubic foot is most suitable. At this weight the ultimate compressive strength averages 400 to 500 pounds per square inch.

Products.

Aerocrete concrete is designed for arch spans up to eight feet. The outstanding characteristics are its exceedingly low weight, resulting in saving in structural steel, ease of placing, sound-proofness, and fire-proofness. The weight of floor, including fire-proofing and steel in reinforcement, beams and girders, is 30 pounds per square foot. The thickness of arch is 4 inches.

Aerocrete is an ideal material for the manufacture of precast floor and roofing slabs. Its low weight results in saving in structural steel while its excellent heat insulating qualities make for small heat losses. Aerocrete roofing slabs present a smooth undersurface and are an excellent base for built-up roofing.

Partition slabs of aerocrete are used for apartment houses, hotels, hospitals, and other buildings in which insulation is of primary importance.

Depending upon the purpose for which it is used, Aerocrete fill can be made in weights from 30 to 80 pounds. The fill is chemically pure, therefore, no danger from corrosion

is experienced when in contact with pipes, etc.

Weight.

Aerocrete can be made to weigh from 20 to 80 pounds per cubic foot. The weight being determined by the use to which it is to be put which is in turn controlled by the amount of gas generated.

Structural Value.

The lightest grades of aerocrete have an ultimate compressive strength of 250 pounds per square inch. The strength increases directly with the weight. Eighty pound aerocrete has an ultimate compressive strength of 1300 to 1500 pounds per square inch. The tensile strength of aerocrete is very small. This material should not be used alone as a structural material, but should be used for its insulation qualities.

The following test, conducted by the Gunvald Aus Company, consulting engineers of New York City, on a panel of finished long span steel aerocrete floor in the Grand Central Gardens Apartments, Fleetwood, New York.

A span of 6 inch "I"-12.5 pounds, 19 feet 9 inches long, 3 feet o. c. continuous over supports, with 7½ inch aerocrete slab, 2 inch aerocrete fill and 7/8 inch underflooring in wood sleepers was selected for the test.

A six foot wide strip on this floor was uniformly loaded with cements bags to 36 pounds per square foot and the deflection was found to be 3/32 in.; the load was then increased to 60 pounds per square foot or $1\frac{1}{2}$ times the figured live load, and the deflection was then measured at 1/8 inch.

The floors were found to be extraordinarily stiff and free from vibration. After the load was removed, the floor construction returned to its original position.

Durability.

Being a concrete product, aerocrete has the permanence of ordinary concrete. It is chemically pure, therefore corrosion will not take place between reinforcing steel, pipes or any metal that comes in contact with the material.

Insulation - Heat.

The quality of heat insulation decreases as the weight of the aerocrete increases. Therefore, the structural value of the aerocrete is the determining factor for the heat insulation value. Seventy pound aerocrete has approximately one-fourth the heat transmission of stone concrete, while the thirty pound aerocrete has approximately one-twelfth the heat transmission of concrete.

The following table gives the coefficient of heat transmission in b. t. u. per hour, per square foot per inch thickness, per degree difference Fahrenheit designated by

C in the table. The standard for figuring equivalent thickness is corkboard.

HEAT TRANSMISSION

Material	Weight cubic foot pounds	C	Equivalent thickness inches	Authority
Corkboard	10	0.30	1.00	Bureau of Standards
Aerocrete	30	0.69	2.30	Peebles-Armour Institute
"	40	1.06	3.54	" " "
"	50	1.49	4.80	" " "
"	60	1.80	6.00	" " "
"	70	2.18	7.27	" " "
Brickwork (dry)	132	4.00	13.33	Willard Lighty & Harding
Concrete	140	8.30	27.70	" " "
Cinder Concrete	110	5.20	17.35	Peebles-Armour Institute
Gypsum	55	1.20	4.00	" " "

Insulation - Sound.

Owing to the porous nature of aerocrete, the interior surface of the material becomes immensely enlarged. Sound waves passing through the material are absorbed by the surface of these cell walls because these waves strike cell wall after cell wall and are subjected to absorption in the surface of these walls as well as being weakened by the inertia of them. For these reasons sound-proofness is one of the outstanding qualities of aerocrete. Numerous tests upon slabs of this material have shown that aerocrete transmits from one-fourth to one-sixth of the sound transmitted by other materials of like composition.

Insulation - Fire.

Due to its high insulating qualities aerocrete is more fire-proof than ordinary concrete. The high insulating qualities make the intense heat from the fire less penetrating and it can withstand the effects of a blazing fire for hours without peeling off, cracking or crumbling.

Insulation - Dampness.

Aerocrete is highly resistant to capillary action due to the fact that each pocket is a separate cell without connections, therefore sucking action does not take place. Surface water is absorbed very readily but penetration is not deep because of the nature of the pockets as described.

Workability.

The technique of mixing and placing aerocrete is identical to that of ordinary concrete except that much less material is required due to the expanding action of the mixture. The mix is placed and then left to expand and harden;after hardened it can be planed or sawed to the required size. Nails are very easily driven into the material thus reducing nailing strips.

Availability.

The compounds of aluminum that produce the aerated action are manufactured by the Aerocrete Corporation of America and its licenses representatives, under their own patents. The compounds are added to the concrete mix on the job.

Uses.

The outstanding features of the use of aerocrete are its smooth surface, exceedingly low dead load, fire resistance, speed of erection and it is practically impervious to sound.

In designing long span steel-aerocrete floors the engineers have succeeded in utilizing its sound-proofness, low weight and fire-proofness to greatest advantages. At the same time, rigid steel only totally embedded in light weight aerocrete is depended upon to take the stresses in the floor. This type is particularly advantageous in apartment houses, schools, hospitals and office buildings. This method of construction was used in such buildings as the Y. M. C. A. (9 floors) at New Haven, Connecticut and the Fleetwood Apartments (9 floors) at Mt. Vernon, New York.

Precast roof and floor slabs and wall partitions of aerocrete have been used in many cases where additional floors are added to buildings after they have been up for a number of years. Such was the case with the Bethlehem Steel Company's office building in Bethlehem, Pennsylvania where six additional floors were added by this method.

One of the largest uses of aerocrete is in fireproofing of structural steel and in floor fills, this use being employed in such buildings as the Chicago Board of Trade Building in Chicago and the Chrysler Building in New York City.

CHAPTER VIII.

GYPSUM

Gypsum is one of the oldest of building materials. The Greeks used gypsum in Pliny's time (23-79 A. D.). The Temple of Apollo at Bassae (470 B. C.) affords an excellent example of the use of gypsum along with its permanent structural qualities. The Egyptian pyramids contain plaster works of gypsum.

Methods of Manufacture.

Chemically, gypsum is hydrous calcium sulphate. It is a widely distributed mineral found in rock formation. The rock gypsum is crushed, ground and then calcined, which drives off a part of the molecular water, forming the hemihydrate or plaster of paris. This product, when mixed with water, takes up or combines with the same amount as was driven off in the calcination process.

The United States Gypsum Company has produced what they call structolite and hydrocal to use where a little more strength is required than pure gypsum can stand. Structolite is an exclusive U. S. G. Company product, which they developed in 1916, consisting of calcined gypsum subjected to certain mechanical and chemical treatments which produce a very dense, high grade product. It is valuable because of its great structural strength and comparative light weight. Hydrocal is produced by special processes that make a quick setting structural cement, basically gypsum, of high wet and dry strength and low absorption.

Products.

Pyrofill (Gypsum Fiber Concrete) consists of gypsum stucco and water and not to exceed 12½% by weight of fiber consisting of wood planer shavings or similar material mixed with 87½% by weight of calcined gypsum. The weight of this when mixed is about 55 pounds per cubic foot. Pyrofill is used chiefly for poured in place system of gypsum floors and roofs.

Pyrobar Gypsum Tile is a precast tile used for non-bearing walls and precast roof slabs. It is composed of 97% gypsum and 3% special wood fiber. The tiles are molded in steel moulds by continuous automatic machine process, which insures accurate proportions and an even distribution of gypsum fiber and water resulting in tile of uniform size, weight, strength and density.

A quick setting hydrocal mastic floor finish has been developed especially for use over gypsum floors, either in precast tile or poured, but it is also recommended for use over concrete, wood, metal or other floors. The floor consists of hydrocal, sand and emulsified asphalt, mixed on the job and poured to a thickness of ½ in. to 3/4 in. as required. A durable mastic surface is provided, highly resistant to dusting, cracking and wear which provides equally as good an underlayment for linoleum, carpeting, etc. For heavy duty industrial floors, gravel is added to the mixture to increase its durability.

Weight.

Pyrobar precast gypsum tile partitions are from 25% to 50% lighter per square foot than ordinary building tile of equal thickness.

Sizes and Weights of Pyrobar Partition & Furring Tile.

Size of Pyrobar Gypsum Tile, In.	For Ceiling Heights up to	Wt. of tile per sq. ft. lbs.	Weight paster 2 sides per sq. ft. ½" grounds	Total weight in lbs. per sq. ft.
1½ in. split 1½x12x30	Furring	4.9	3*	7.9
2 in. split 2x12x30	Furring	6.4	3*	9.4
2 in. solid 2x12x30	10 feet	9.4	6	15.4
3 in. hollow 3x12x30	13 feet	9.9	6	15.9
3 in. solid 3x12x30	15 feet	13.0	6	19.0
4 in. hollow 4x12x30	17 feet	13.0	6	19.0
5 in. hollow 5x12x30	20 feet	15.6	6	21.6
6 in. hollow 6x12x30	30 feet	16.6	6	22.6

*Plaster on one side only. No underwriter's recommendation.

Weight of Fireproofing Per Lin. Ft. of Beam in Lb.

Size of Member	Precast Gypsum	Clay Tile	Concrete
6 in. I	19	33	60
7 in. I	21	36	71
8 in. I	23	39	93
9 in. I	25	43	95
10 in. I	27	47	118
12 in. I	30	51	131
15 in. I	35	60	168
18 in. I	42	68	208
20 in. I	44	73	234
21 in. I	48	79	293
24 in. I	52	85	297
27 in. I	58	96	392

Pyrofill slabs weigh 55 pounds per cubic foot. A 3 inch slab will weigh 12 pounds per square foot, while a 5 inch slab weighs 20 pounds per square foot.

Structural Value.

Pyrobar floor and roof tile are designed to develop the full strength of the supporting steel. They will safely carry a uniform load of 150 pounds per square foot with a safety factor of four which is ample to take care of such buildings as theaters, apartments, hotels, schools and office buildings where they are most generally used.

An example of a test upon pyrobar roof tile is afforded by the transverse bending tests made on short span tile at Columbia University in 1922. In these tests the load was applied at the third points until failure was produced. For the 3x12x30 inch solid short span pyrobar tile, the total load applied at the third point averaged 1020 pounds. This represented an equivalent uniformly distributed load of 545 pounds per square foot.

The theory of design of pyrofill monolithic gypsum floors and roofs is to transpose the live or superimposed load to steel cables by the gypsum slab, the cables carrying the load. Tension in the cables, due to the superimposed load is transmitted to the end purlin or beam and is taken up by the bracing members. The cables are securely anchored at both ends by means of bent strap iron of sufficient strength to resist the maximum pull of the cables.

The cables are put in uniform deflection and tension by 5/8 inch round deflection rods. The cable spacing varies from 1 inch to 3 inches depending upon the span and live loads.

Durability.

Pyrobar and pyrofill being composed only of gypsum and a small amount of wood fiber, there is no acid in alkali to stain plaster or wall decorations.

Sulphur dioxide gas is commonly encountered in manufacturing plants, forge shops, foundries and power plants. Most structural materials are readily attracted by these gases which invariably lead to their failure. Authentic tests upon reinforced gypsum roofs show that they have a strong resistance to sulphur fumes, therefore making its use as roof slabs and protective coating of structural members ideal for such places as mentioned.

Insulation - Heat and Cold.

Gypsum, with its close knit air confining cells, has the highest insulating value of any fireproof cementitious structural material, thereby combining insulation and strength into one homogeneous substance.

Conditions of the present demand a material for roof deck that is equally as good to maintain a cool condition in the summer as to conserve heat in the winter months.

In the following table the values of heat transmission of pyrofill roof deck covering is given in b.t.u.s per hour, per square foot, per degree difference in temperature, all roofs figured with a five ply roof covering.

$2\frac{1}{2}$ in. Sheetrock Pyrofill	.35 b.t.u.s
3 in. Sheetrock Pyrofill	.318 b.t.u.s
$2\frac{1}{2}$ in. Insulating Board-Pyrofill ($1\frac{1}{2}$" board)	.252 b.t.u.s
3 in. Insulating Board-Pyrofill (1" board)	.182 b.t.u.s

In tests conducted by the Bureau of Standards, the length of time that was required for a temperature of 600° C. was noted to be reached at a depth of one and one-half inches from the surface. Out of twenty-eight specimens of pyrobar tested, only one reached the temperature of 600° C. at the end of a three and one-half hour test. Therefore, this shows superior qualities as a thermal protection for embedded steel.

<u>Insulation - Sound.</u>

Gypsum tile partitions are excellent non-conductors of sound and are recommended and successfully used in hospitals, schools, office buildings, apartments, hotels and other buildings where sound-proofing is essential.

Unless a partition is constructed for sound-proofness a large percentage of the sound-proof qualities are lost through doors, continuous floors, etc.

<u>Insulation - Dampness.</u>

Wherever gypsum is used and will be in contact with water, there should be provided a water-proof covering, as the insulating qualities are far superior to its water resistant qualities.

Insulation - Fire.

The temperature of a slab of gypsum, whether poured or precast, cannot exceed 212^{o} F. except on the surface exposed to the fire. This is due to the fact that the water or crystallization in the gypsum slowly calcines and the cellular structure of the material fills with steam. It is this barrier of calcined material which stubbornly resists the progress of the fire.

Workability.

The large lightweight units are easily and speedily erected in any kind of weather in which it is possible to work. The tile is laid directly on the supporting steelwork and requires only the grouting of joints to make the roof ready for the water-proof covering. This can follow immediately, materially shortening the construction period. Maintenance is practically nothing.

In the case of field mixed,pyrofill can be used to best advantage with spans of approximately eight feet between mainpurlins with a 2½ in. slab thickness. When channels are used on sloping roofs, they should open upward in order to permit proper clipping. On roofs with a slope of 45^{o} or over it is necessary to back form from top in order to obtain a satisfactory job.

Availability.

The gypsum products described are standard products of the United States Gypsum Company and can be obtained throughout the country from their large sales organization.

Uses.

These constructions are especially adapted to buildings where floor loads are light, such as apartments, hotels, schools, office buildings and theaters in connection with lightweight floor members. The 3 in. solid pyrobar slab is recommended particularly for nailing purposes because it assures maximum penetration and thus possesses the greatest nail-holding ability. The 4 in. hollow tile is best used for its insulating and structural properties to be covered with built-up roofing. The short span affords the greatest amount of flexibility of all precast units.

Pyrofill monolithic floor and roof construction is adaptable for practically any type of roof; on flat, saw-tooth or others it will be found to work equally as well. This type of construction is generally applicable to floor construction. Because of the heavier loads met with in floor design compared with roof design, it is recommended that spans should not exceed 6 or 7 feet with slab thickness of 3½ or 4 inches.

Fifteen years of constructing these types of gypsum products has placed over 100,000,000 square feet of gypsum roofs in use.

CHAPTER IX.

CONCLUSION.

New materials may be classified under two general headings: those which are evolved from present methods and those which are revolutionary in character. Illustrations of gradual evolution include various types of concrete blocks, hollow tile or other substitutes for brick; wall boards in place of plaster; and steel studs or concrete lumber in place of wood framing. There are three outstanding developments in the building industry which can be classed as revolutionary in character which are (1) the development of reinforced concrete construction; (2) the use of a steel frame which permitted the development of the modern skyscraper and (3) the use of various forms of sheet metal walls. Until recently sheet metal, usually corrugated iron, has been used only in factories, warehouses, farm buildings, garages and various types of temporary structures, but now sheet metal is coming into quite general use in all types of buildings for partitions, and spandrels, experiments being conducted at the present time to find the possibilities of using metal for exterior walls of homes.

The use of magnesium and aluminum is of the revolutionary nature when used for walls and spandrels. While used structurally, they are an evolution of the steel frame. The use of the different kinds of lightweight concrete and gypsum is of evolutionary nature because they are just a further development of existing methods of construction.

There are many outstanding features found in the use of lightweight material other than the reduction of the dead load.

One feature closely related to the weight of the material is the ease of handling and placing the material. A good example of this is shown by the extruded window and pier erection methods used in the construction of the A. O. Smith Corporation Building of Milwaukee, Wisconsin. In this novel design it was necessary to depart from the usual construction methods in that no scaffolding was necessary for the erection of the aluminum, thereby reducing the cost of erection not to say anything of the time saved. Only 15 days were required to enclose the elevations of this seven story building and because of the revolutionary construction methods it is assumed that a similar building could be enclosed in ten days. It would take at least 50 days to enclose this building if a brick or stone facade were used. This shows a gain of forty days time which means a saving in the labor costs as well as a reduction in the time of construction of the entire project thereby making it possible to realize a sooner return on the investment.

No one realized the importance of time taken for construction purposes more than the owners of the New Empire State Building in New York City. This is the largest building of its kind in the world, yet it was designed, erected and completed for occupancy in a brief period of eighteen months. The land upon which this building is placed is reported to have cost $16,000,000 or more than $8,000,000 per acre. The project involved a cost of $50,000,000. On an investment of this sort the interest on the entire investment would amount to approximately $3,000,000 a year or over $8,000 a day.

Metal for partitions and exterior wall units are more easily able to be produced by complete machine production than wood, steel stud or block wall with plaster finish. Unquestionably factory finished partitions and wall units would minimize the field work but additional care and expense would be necessary to ship these units to the job without marring the surface.

The special handling of material was shown by the care necessary in placing the structural aluminum in the New Botanic Gardens, Washington, D. C. Because the beams were to be left as placed without any finish coat of paint it was necessary to use ropes in placing the structural shapes of aluminum in order to prevent marring the surface.

Lightweight material makes possible the use of thinner walls thereby increasing the rentable area of the building. In the case where rentals are figured by the square foot of usable floor area the use of thinner walls would amount to a considerable figure for the owners.

By the reduction of the dead load in a building it means a reduction in the size of the supporting structure. Other cases where expansion is anticipated at the time of the original design at the time of expansion design, it is possible to add an extra floor or two by the use of lighter materials in the construction of the expansion than were allowed in the original design. This has proved a great saving in many cases.

Because of the nature of these materials used to produce the lightweight, most of the lightweight concrete is more fireproof and sound-proof than regular concrete. The lightness is due to the air voids in the aggregate or in the concrete itself. These air voids are surrounded by thin walls, thereby producing entrapped dead air. Dead air is one of the best methods for stopping the passage of heat or sound.

This porous nature of the concrete also prevents sucking within the slab or unit, thereby increasing its resistance to moisture. When a wall is made of units of precast blocks the porous nature prevents the drying out of mortar bed and making a tight joint by producing a good bond.

It has been found that concrete of lighter weight is more flexible than ordinary concrete. This tends to reduce the cracking resulting from undue stresses placed on the material.

Nailability is considered one of the most convenient features found in concrete of lighter weights. The placing of nailing strips is an important job and can be done away with entirely, for the bond between wood and a nail and porous concrete and a nail has been found to be nearly the same. Corrosion is eliminated within the concrete so the bond is everlasting.

In the case of stone aggregates it is important to control the mix so the stones will not sink to the bottom and remain leaving the smaller material at the top. The control of the mix is just as important in the case of lightweight aggregates as in stone aggregates only the results are just the opposite. In the segregation of the materials, due to a sloppy mix the lightweight aggregates float, producing a poor grade of concrete.

It has been found that some of the lighter materials have greater corrosion resisting properties than some of the more commonly used materials. In places where the cost of maintenance is high, due to the care necessary to keep the materials in condition, it would cost less in time to place non-corrosive material, even at a higher first cost. This was done in the Botanic Gardens in Washington, D. C. The aluminum purlins and structural members in the palm house roof were selected because of their low maintenance cost, which is practically nothing, as these members are not even painted.

In general, it may be said that lightweight material has a decreasing structural value but increasing insulation, resistance to corrosion and fire resistance values, also the ease of working handling and placing has been improved to a large degree.

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