Development of Cement Use
Manufacturing Processes and Product Qualities

by G.M. Idorn, Copenhagen

Features of past and present development of concrete technology and uses in Denmark will be mentioned to exemplify the general trend showing that industrial processing and product development is about to improve the utilization of cement considerably, compared with what has been feasible in conventional engineering practice for many years.

Industrial monitoring of cement hydration, compaction technology and effects of admixtures etc., will be mentioned as part of this broad field of innovation.

The importance of such progress for conservation of materials and energy resources, and the perspectives will be discussed.

The demands on research and development to offer effective support to further progress and the communication and management aspects involved will be discussed.

The attitude of Danish industry to intensified international exchange and cooperation will be presented.

Opening remarks

It is a great pleasure and privilege to present some features of recent Danish development within the field of concrete technology in this part of the world. In Denmark, East Asia is spoken of as the Far East. Probably, seen from here, Denmark forms part of the Far West.

There is an old Danish saying: "East, West, home is best." But this is not true any more. As far as technology and its development is concerned no country, industry or research can fulfil its demands on progress by means of its own resources alone.

The reason why Danish accomplishments are emphasized in the present discourse is therefore that this is what the title promises it to be about. It has not been possible to fully documentate how much the Danish research and development owe more basic or applied efforts in other parts of the world. This documentation has been done elsewhere, but in fairness one must mention that not least the major part of basic science and research on cement and concrete has always primarily been executed in countries bigger than Denmark. The participation in international exchange therefore forms an ever important part of the development, and this comes more and more true anywhere in the world.

Thus, there may be many advantages by bringing the Far East and the Far West closer to each other.

I do hope that my contribution may be helpful in this respect, so as to become the response your invitation deserves.

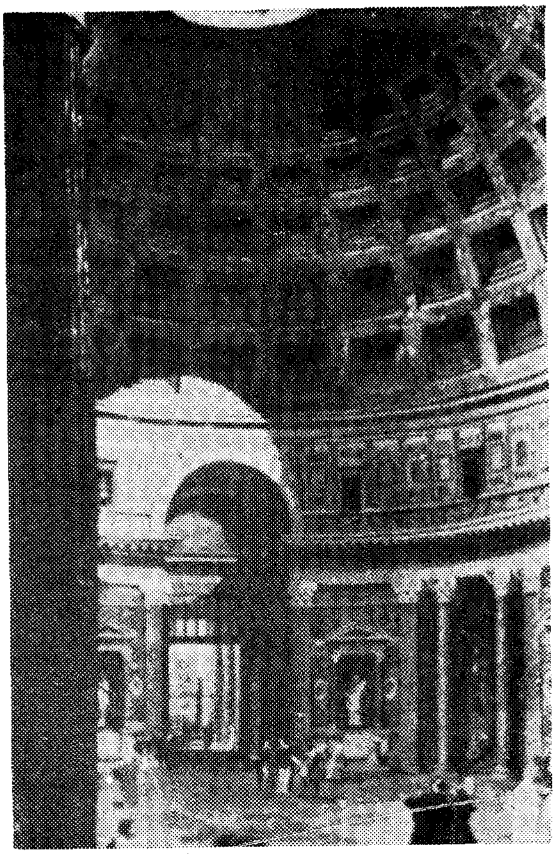
Introduction

Thousand years ago the most of Denmark was a wilderness and its population was feared in Europe as barbaric, daring buchaneers. At this time concrete had already been known another thousand years in Mediterranian Europe and had been a fundamental building material in the Roman civilisation.

Roman concrete, now approaching 2000 years of age, still stands, see Figure 1, to remind us that the development of concrete went through a very long spell of stagnation until industrialisation took on in the 19th century. Until then, building and construction had satisfactorily relied upon local resources of wood, clay and boulders or hewn stones and lime mortars.

But when large scale manufacturing and transportation of materials and products became possible with the invention of the steam engine, the need arose also for availability of huge quantities of inexpensive building and construction materials.

Portland cement was then also invented and its use was further escalated when the



<Figure-1> The builders of the Roman Empire developed concrete to be a material of outstanding versatility and of excellent durability, as documentated by the existence today of many Roman structures made in concrete. Roman cements were mixtures of lime and carefully selected pozzolanic sands. Manufacturing of cements, mortars, and concrete were based on strict regulations and high skill of the craftsmen.

rotary kiln came into the picture in the USA about 1880.

However, this would in itself have had little effect, had not civil engineering concurrently developed the technology and use of mass concrete and reinforced concrete as very versatile construction materials. They could match the feasibility of earlier introduced engineering materals like wood and cast iron, and reinforced concrete utilized steel effectively compared with steel constructions.

One may say that the invention of reinforced concrete represents the first significant materials resource conservation in the engineering development.

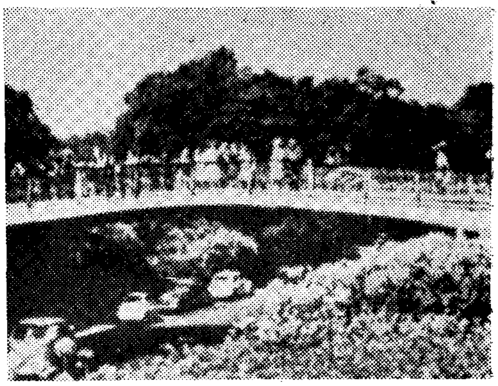
Engineering skill in design theory and in construction practice is an impressive feature in the history of concrete development, which, however, also owes much to the craftsmanship of the man on the site.

Computers, television, vitamins and X-rays etc. were conceived in modern sciences aided by industry instrumentation, in contrast to concrete, which can be said to have grown out of the hands of skillful workmen and foremen in team work with site engineers.

Thus, even up to our days, concrete making is solidly anchored in the traditions of the building crafts and benefits from their pride in quality and reliability. This is still worth while to care for, although the strong dependence on this evolutionary practising sometimes also constitutes barriers against innovations which modern sciences offer but must often present as strange contrasts to the conventional, experienced procedures and habits.

Figure 2 is an early, remarkable Danish civil engineering and concrete workman achievement, the Ostenfeld Bridge at the Copenhagen habour, incidentally located nearby the little mermaid, which for obvious reasons is far more famous.

This foot-bridge was erected in 1894 and is still used. It stands as a monument of the capability concrete possesses to be shaped as an entity by rational performance criteria and architectural perceptions of beauty. This integrationof technique and art is a feature of uslture which ought to be kept in high regard



<Figure-2> The Ostenfeld Bridge near the Langelinie pier in the Copenhagen harbour. Built 1894, designed by the late professor A. Ostenfeld, who pioneered engineering design in general and theories and experimental research regarding reinforced concrete for several generations of Danish civil engineers.

at any enterprise and concrete technology development.

The Ostenfeld Bridge was made with a portland cement offering only about half or less the concrete strength of modern cements, and with considerable strength variations. Indeed, it happened that the wood barrels in which cement was stored in those days swelled and collapsed because excess free lime absorbed humidity and hydrated. Very detailed control systems regarding the quality of the concrete and its materials were therefore part of the daily engineering tasks and also of the education of civil engineers.

Over the years this engineering site control has evolved into the vast present systems of standard specifications. Their elaboration and perfection of control and regulations have grown to become trades almost in their own rights. This has peculiarly enough happened parallel with a perfection of cement manufacturing technology which now provides so high and even cement qualities that failures to meet the standard requirements do not need to be more than rare exceptions. External control may thereby become added cost for industry and customers rather than savings or safeguards.

Price (1) presented a vivid description of how the conventional control policy in the USA can now disturb the industry rationalisation and the desire to provide the most adequate cement quality to the proper utilization. Countries not yet quite entangled in the grip of standard regulation power should be aware that a liberal standard specification policy may prove both necessary and profitable for further industrialisation of cement use. Especially with regard to cutting down the time lag for introduction of new developments in practice.

Price mentioned in his paper a growing concern in the late 60'ies among US cement industries regarding a spiralling increase in the fineness of cements offered to the market because emphasis from customers focused on maximum cement strength output. It is interesting that some of the industries involved produced cements which gained strength rapidly and then flattened off, while others were more slow though steady and equal at 28 days' strength levels. "If the steady gainers to compete on early strength requirements ground finer, they also raised their ultimate strengths."

Thus, the fractionwise increase in the cement quality in the end became less related to the real demands of the customer: The optimal quality of his concrete structure.

The fine-grinding spiral has been settled in the said area of cement production and use because it became clear that the procedure chosen was in fact a matter of "lifting oneself by the hair."

The Ostenfeld Bridge is still, after more than 80 years' uninterrupted service, excellently serviceable. Undoubtedly, the cement used has been coarsely ground. There has therefore initially been a considerable quantity of unhydrated cement confined within the hydrated cement paste, and it is rather certain that the concrete has been under slow but continuous hydration and strength increase for many years after its making. This can well have matched wear and tear, yes even have enabled autogenous healing of fracturing deriving from the use of the bridge.

Such improvements of the performance characteristics have not been accounted for in the original specifications and control criteria.

Even in modern uses of cement the degree of hydration in practice probably rarely exceeds 50 to 60 per cent, which means that up to half the cement used is utilized merely as an inert filler—not as the excellent gluing material it is made to be. As experiences show, some of the unused cement will hydrate in the course of time and thus become useful. On the other hand, there are industrial cement product technologies by which less than 50 per cent hydration be attained because heating and drying are applied for reasons of process economy. If such products are exposed to weathering over years of service, the hydration may go on slowly, thus matching wear and tear. If other types of products are exposed only to continuous drying out—for instance used only at indoor exposure—a low degree of hydration may not matter.

However, in any case a low degree of hydration does mean inefficient output of the resources bought into the cement during its manufacture. And technology development should attempt to decrease such waste.

In fact, it is an interesting thought that modern standard specification policy might focus on requests to "degree of hydration" differentiated in relation to the manufacturing technology by the use of cements. This would make manufacturing methods rewarding which increase the effective utilization of the binding forces in the cement.

It seems justified in this way to formulate quantitative challenges to the further development of effectiveness in the use of cements, also because the last 25 years in so many respects represent great achievements with cement and concrete with emphasis on design and construction, but utilizing the concrete itself, "as it is", or—in other words—with no demanding new requirements to the materials' characteristics.

Recent Danish contributions in concrete

Civil engineering has made impressive progress in many parts of the world in skyscrapers, bridges, highways and tunnels, nuclear power plants, off-shore platforms etc., in which areas Denmark is too small to become a field of extraordinary operations.

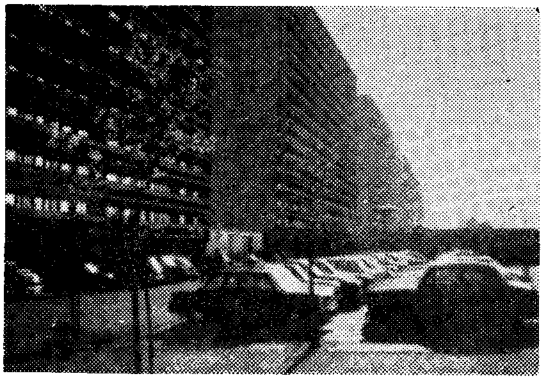
<Figure-3> The Bellahoj multistorey flat scheme was among the first comprehensive precast concrete housing schemes in Denmark. Extensive experiments on design and construction methods were involved. Now 20 years old.

But modern Danish housing schemes are deservedly the subject of broader attention.

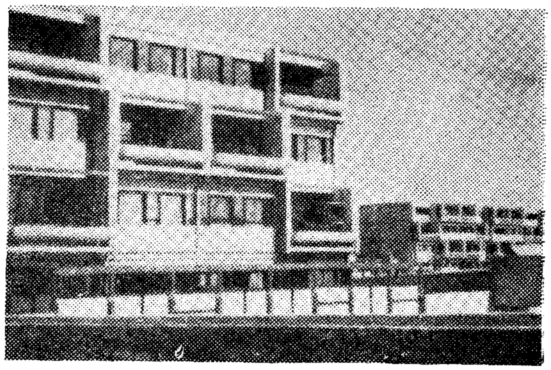
Figure 3 shows an early example of tall multistorey flat buildings in Copenhagen, built about 1955 to 1957.

Figure 4 is the peak of well planned high-multistorey flat housing schemes, built in the mid-60'ies. The demands on dwellings still at this time motivated sky-scrapering to 16 floors. Experiences, especially concerning the life of small children have soon made this type of houing obsolete.

Figure 5 is a more recent scheme. Extreme heights have now (about 1970) succumbed



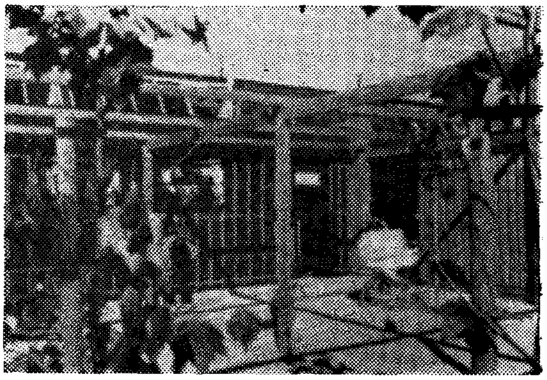
<Figure-4> The Gladsaxe multistorey flat scheme on the western outskirts of Copenhagen. Elaborate design development and construction rationalisation based on the modulus principle and on advanced utilization of precast concrete. Now about 12 years old, and not favoured any more, as consumers' taste find the environmental quality of the "high-houses" inferior to living "closer to earth".



<Figure-5> The "Brondby Strand" (Brondby Beach) about 20 kilometres south of Copenhagen. Built about 1970 and known for its high quality and big size of apartments, but also for rents running into prohibitive heights for the tenants. The precast concrete industry shows considerable ability to develop production in accordance with the architectural views and wishes.

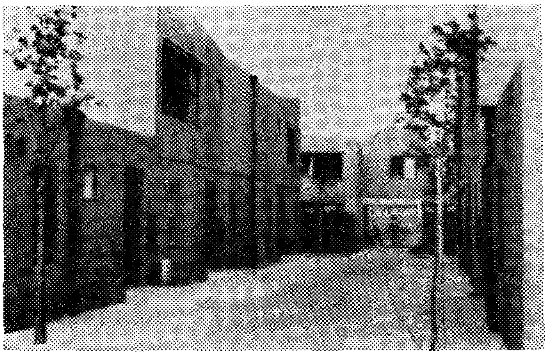
to bigger apartments and better facilities. This particular housing scheme in fact became so expensive that it got problems finding tenants who could pay the rents.

Figure 6 shows a more recent development in Danish dwelling schemes. Without sacrificing any of the advantages of industry manufacture of precast concrete panels and other elements of construction, there has now been added a higher quality of total planning. Due regard is shown the creation of a socially attractive environment. Certain of the pre-industrialisation "village"-character is being re-created in this habitation. This is a Danish reflection on experience, which says that throughout a century "the big city habitation customs" also encompass certain antihuman features, not least for the proper education of children and for pleasant relaxation on the part of the older generation.



<Figure-6> The "Galgebakken" (The Gallows Hill!) some 20 kilometres south-west of Copenhagen. A vision of the old village-life with close human associations is here realized successfully on the basis of industrialised precast concrete manufacture and use.

Figure 7 shows another equally modern housing scheme, like the one before built near Copenhagen some 3 to 4 years ago.



<Figure-7> ..ne "Hyldespjældet" (not translateable) another new "dense, low" habitation scheme some 30 kilometres south of Copenhagen.

This recent Danish development of village/town planning based on long-term experienced qualities of human life and modern industrial production methods are presumably of interest to many developing countries.

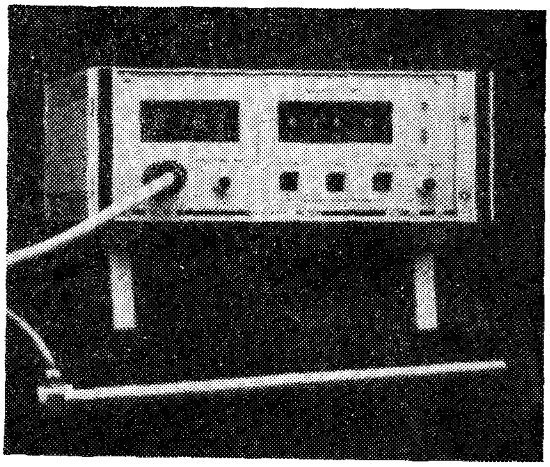
The development of the precast concrete industry in Denmark brought the house building capacity up towards 70,000 dwellings a year or about 14 dwellings per 1,000 inhabitants, a remarkable feat of trade and industry development achieved concurrently with the cement consumption passing 500 kg a year per inhabitant.

The economic recession since 1973 has enforced a thorough phase of reconsideration of this development. Firstly, the production of dwellings has decreased to less than 30,000 this year. Secondly, since energy prices are soaring, and 40 per cent of the energy consumption in Denmark is used for heating, there is a movement towards more insulation for fuel-saving purpose than ordinary concrete walls can provide. (Speaking about energy conservation it is interesting that there is much energy which can rather easily be saved by insulation of houses, industry plants etc., so as to cut down on the 40 per cent of the total consumpion. In contrast, the entire cement manufacture represents only about 2 per cent of the total energy consumption, and thus has much less weight in the national energy conservation scheme, although also the cement industry aims at developing into technology with less loss of energy during the manufacturing process).

Besides the energy problems also the materials' resources are coming into focus. National surveys have disclosed that the deposits of quality concrete aggregates in Denmark will be used up in about 50 years if the present consumption be maintained.

These features are significant elements of a total picture which invites the Danish Building Industry to exploit how the demands on energy and materials' conservation can be met by improvements in the technology of cement use in concrete and in other cement products.

Concrete technology development



<*Figure-8*> *The MATURITY COMPUTER manufactured by the Danish firm of C. Thiim A/S on the basis of a pilot model by P. Freiesleben Hansen, C.E., and comprehensive research on hydration, performed at the Concrete Research Laboratory, Karlstrup, Denmark.*

One conspicuous instrument in this development is the MATURITY COMPUTER, see Figure 8. It has been known for many years that heat is developed during the hydration of cement paste, or in other words, during the curing of concrete, and concurrent with the strength development. In fact, early American investigation, Verbeck et al(2) identified the quantitative dependance of strength on the heat of hydration.

Accordingly, it is selfexplanatory that although 20° Centigrade is for convenience a common reference temperature for curing of concrete under examination and testing, the strength development will be accelerated when the temperature in concrete exceeds 20° Centigrade, and decelerated when the temperature goes below 20° Centigrade.

If one can measure the real temperatures throughout the hydration process, and recalculate the accelerations / decelerations going on to a reference heat of hydration development at 20° Centigrade, then one has at any time the true picture of the actual stage of the hydration-the so-called degree of hydration.

This is what the Maturity Computer can accomplish.

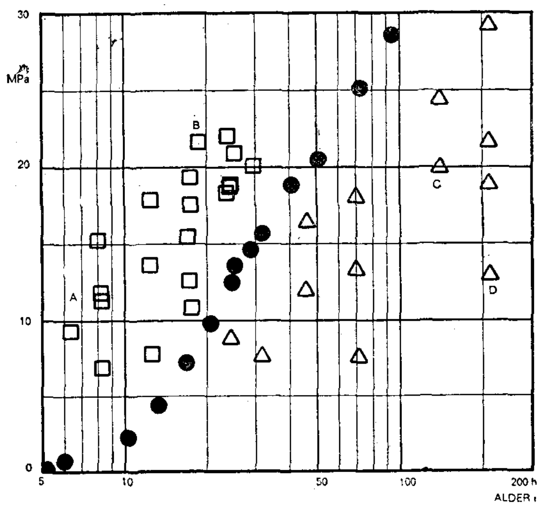
The maturity computer has a temperature senser positioned in concrete just after casting. The instrument then records the temperature development in the concrete continuously. On a digital display one can read:

1. The equivalent degree of hydration at 20° Centigrade
2. The differential growth of maturity per time unit
3. The degree of hydration in percentage of a predetermined level.

This means that the instrument in an industrial manufacturing process can function as a continuous recording of the hydration process in concrete or in other words of the strength development. It can also show the effects of accelerated curing measures, as for instance steam curing, because speeding up of the temperature inside concrete comes out directly on the display as gain in degree of hydration, equal to strength. The readings can be preset to show proper demoulding time. Quality variations of cement can be eliminated in the concrete strength development, and so can waste of heat for curing, because it can be calculated whether the cement hydration itself produces sufficient heat for the prescribed strength development.

Through long periods of trials the maturity computer has proved to enable savings of about 5 dollars per metric ton cement used in precast panel plants. This saving is accumulated by reduced costs to heating the concrete, reduced cement contents to provide for the prescribed strength, shortening of curing time, adjustment for variations of cement characteristics and, in general, improved productivity among the workers due to reliability of the readings compared with "thumb-finger-rules."

Figure 9 is an example of test results showing the strength gain of concrete in the temperature range from—10° Centigrade to 20° Centigrade. The results reproduced in this graph comprise 47 different hardening processes. Each point plotted in the graph represents the mean value of 3 compression tests. From P. Freiesleben Hansen and Erik



<Figure-9> Example of test results showing the strength gain of the concrete in the temperature range from −10 to 20° Centigrade. The results reproduced in this graph comprise 47 diffe rent hardening processes. Each point plotted in the graph represents the mean value of 3 compression tests. The points A, B, C, and D refer to the respective temperature-time curves shown in Figure 10. Rapid hardening portland cement content 325 kg/m³. Water-cement ratio 0.52. Natural gravel and sand aggregate.

● Isothermal curing, 20° Centigrade

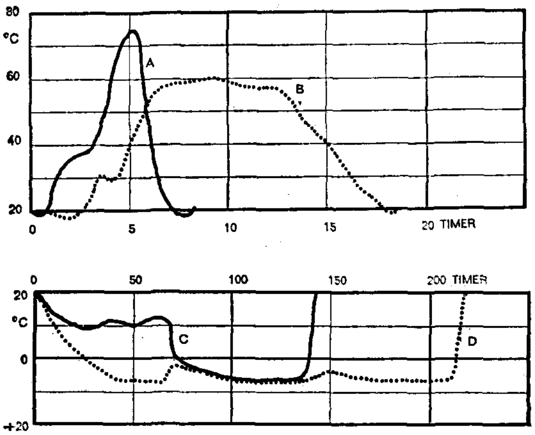
□ Heat curing, 20 to 80° Centigrade

△ Cold curing, −10 to 20° Centigrade

J. Pedersen(3).

Figure 10 shows four examples. A,B,C, and D, of temperature—time curves used in the hardening tests represented in figure 9. (From (3)).

In ordinary compressive strength tests the temperature—time dependance is not involved, because curing is at 20° Centigrade.



<Figure-10> Examples of temperature-time curves used in the hardening tests which are represented in Figures 9 and 11. The curves A, B, C, and D resulted in the values of the compressive strength which are shown in Figure 9.

Temperature of the ambient storage water, and the concrete temperature is not recorded. Therefore, conventional strength tests reflect uncontrolled and always varying maturity, that is to say no logical physico / chemical relationship between the composition of the concrete and its strength characteristics.

Figure 11 shows, on the contrary, how application of the maturity computer brought afore the logical relationship between the inherent heat / strength development and the cement hydration energy in the concrete. Now one can see that isotherm hardening at 20° Centigrade is identical with accelerated hardening by elevated temperatures as well as with colder, slower hardening - if all values are measured by means of a proper temperature-time relationship, the MATURITY.(From (3)).

It ought to be said that temperature-time functions were identified scientifically as early as in the forties by Lea-Nurse and others, see e.g. Idorn(4), but only recently by P. Freiesleben Hansen made feasible for use at higher temperatures than 20° Centigrade in connection with development of the MATURITY COMPUTER.

The older maturity functions were all developed on the basis of hydration studies at 20° Centigrade or less, and applied successfully in winter concreting practice in many countrieses.

P. Freiesleben Hansen introduced the Arrhenius equation for thermic activated processes:

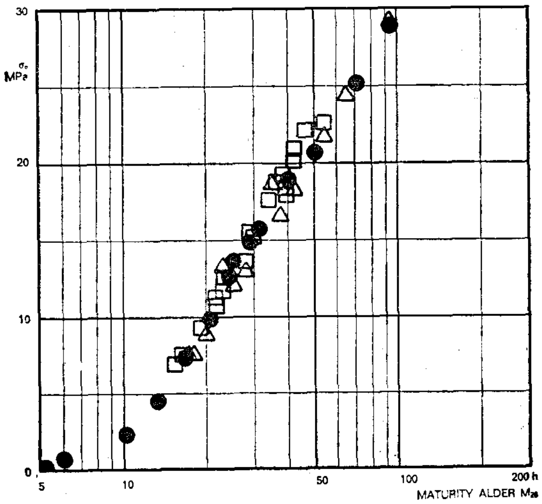
$$f(\Theta)=k\cdot\exp\left(-\frac{E}{R\cdot T}\right)$$

Where: E=experimental activation energy (kJ/mol)

R=gas constant (kJ/mol°K) .

T=absolute temperature (°K)

k=proportionality constant



<Figure-11> *Example showing results of laboratory tests on a MA-10 Maturity Computer. This graph represents the relation between the results reproduced in Figure 9 and the maturity age, M_{20}, which was recorded by a MA-10 Maturity Computer during the hardening tests. In these tests, the sensor was placed in a control specimen, C 10 cylinder, which accompanied the test cylinders in each individual test.*

● *Isothermal curing, 20° Centigrade*

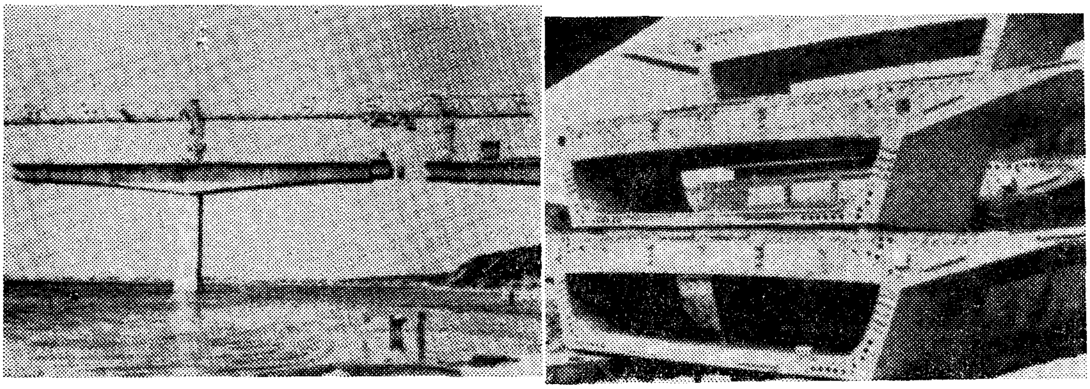
□ *Heat curing, 20 to 80° Centigrade*

△ *Cold curing – 10 to 20° Centigrade*

and conducted intensive research, both basic and applied, for examining the validity of this temperature function, whereafter he also initiated and took part in the construction of the maturity computer which transfers the concrete temperature development into "degree of hydration" or *maturity*.

Experiences gained by introducing the maturity computer on construction jobs have shown that hardening concrete is more often than generally known exposed to deleterious stresses deriving from too high differences between ambient air-temperatures and the internal concrete temperature, increasing at early ages due to the hydration process.

Figure 12 shows a new bridge under construction in Denmark. A critical optimalisation of the progress of casting, heat curing and transport to storage of each element was



<Figure-12> *The Sallingsund Bridge under construction in Jutland, Denmark. Each bridge element is cast under maximum possible rate of strength development, so as to minimize erection costs as much as possible. The maturity computer has proved an effective instrument to ensure against development of aggravated temperature stresses with the pressure put on the speed of manufacturing.*

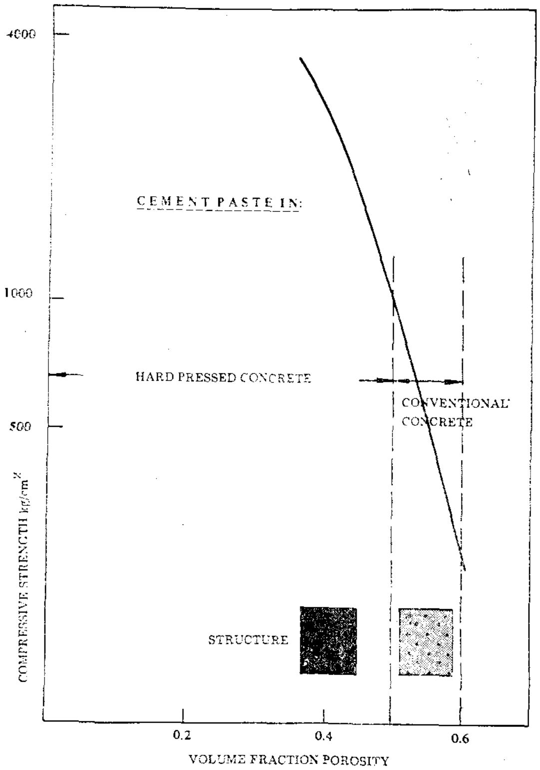
achieved, when the maturity computer was applied, so as to offer effective control against early cracking imposed by temperature stress.

As part of such monitored curing procedures, which are now penetrating Danish concrete industries throughout, it is observed that one must also avoid mixing temperatures beyond 45–50° Centigrade, too early heating to beyond 40° Centigrade, and excessive heating in attempts to obtain early strengths to more than 60–65 per cent of the ultimate strength required. All these influential parameters must and can now be controlled and monitored with input for continuous process registration which reflects the true features of what goes on in the concrete.

The conventional standard specification and their empiric tests do not reflect more than a few – easily measurable, but not primarily influential – strength development parameters. Other tests – based on drilled cores from concrete to be controlled – may well reflect the true strength characteristics of the said concrete – but only at a late stage with no adjustment possibility.

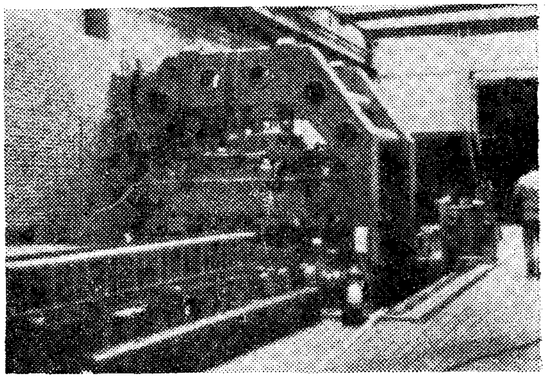
Figure 13 reveals another important characteristics of concrete making, the volume fraction porosity of cement paste in concrete as related to compressive strength of concrete. It can be seen that conventional concrete is a relatively porous and therefore weak material compared with what theoretically can be achieved by optimum compaction.

Figure 14 shows a new Danish compaction machine, VIPRES, for the manufacture of precast panels. It is based upon research carried out by H. H. Bache (5). The principle



<Figure-13> *Volume fraction porosity of cement paste in concrete. Most concrete is conventionally produced to possess a volume fraction porosity of 0.5 to 0.6 and a comparable compressive strength much less than can be attained by more effective compaction of the fresh concrete.*

of this particular vibratory machine is that it combines deliberately chosen combinations of simultaneous static and dynamic load. The combined load is exerted in 90 seconds, whereafter the concrete can be instantly demoulded. The rate of production is thus exceptionally big. This means that a plant for precast panels of a capacity of 1,000



<Figure-14> *The new Danish VIPRES concrete panel manufacturing machine based upon the principle of simultaneous static and vibratory load, exerted during 90 seconds Demoulding takes place immediately after compaction. Considerable strength improvements or savings of cement can be obtained, compared with ordinary precast concrete panel manufacturing methods.*

dwellings a year will need an area of 3,000 m² and a staff of 60 to 80. A comparable conventional plant would require 6,500 m² and a staff of 110.

Besides, the effective compaction makes a saving of 30 to 50 per cent cement possible, or 3 to 5 USdollars per metric ton cement.

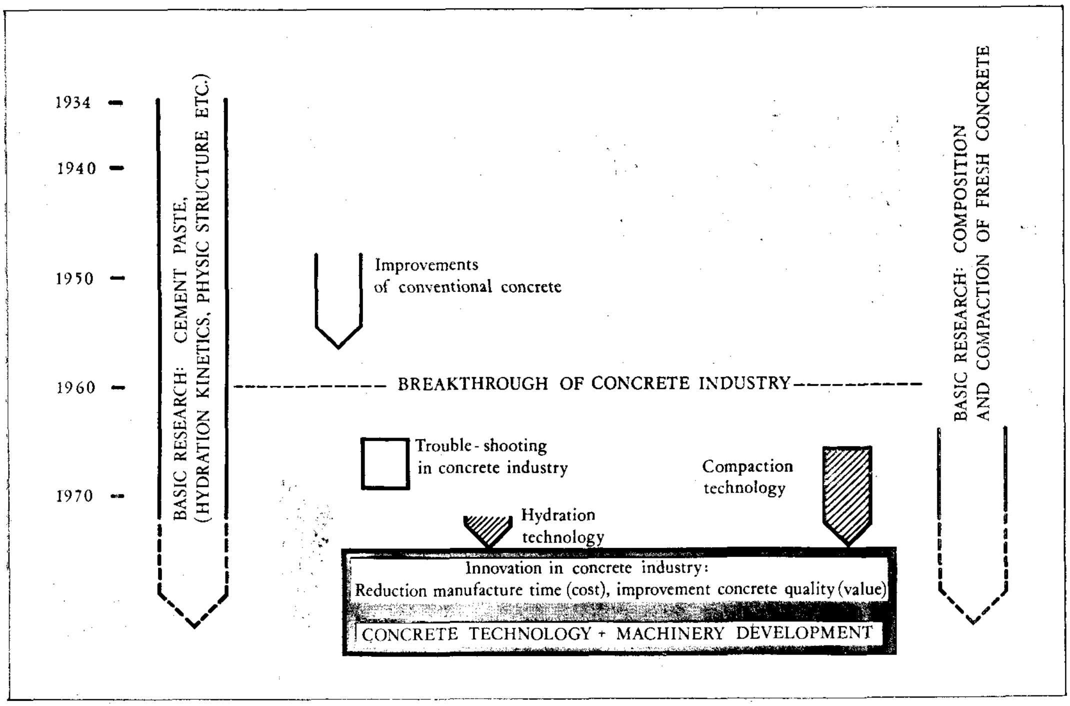
The described development of hardening/curing control and of a new concrete compaction machine form quite outstanding part of progress within modern concrete manufacture technology.

Figure 15 shows a configuration (from Idorn (6)) of this combination of "monitored hydration" and a new compaction technology. Altogether this has absorbed investments of about 30 mill. Danish kroner, equal to about 5 mill. US dollars. The attainable earnings can be estimated to be about 7 to 10 US dollars per metric ton of cement used.

The Danish precast concrete panel industry absorbs about 12 per cent of the Danish cement consumption, or at present about 240,000 ts cement per year. If this in its entirety fully exploited the above improvements of hydration and compaction technology, the savings would amount to an order of magnitude of 8 to 10 US dollars x 240,000 ts, or about 2.4 mill US dollars per year.

Realistically, such savings should be weighed against the necessary investments in instruments and machinery, and in intense education and training of people. Therefore' the innovations will require some years of production service to prove the economic feasibility.

However, the advances described are not confined to become effective in the precast panel line of cement consumption, but is probably applicable for close to 50 per cent of



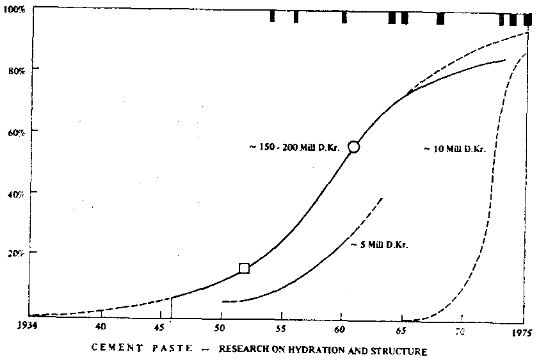
<Figure-15> A configuration of combined research and development regarding cement hydration and compaction of concrete, carried out and implementated in Denmark during the concurrently with the building up of the modern precast concrete industry. The underlying 50'ies and 60'ies basic research on cement hydration and on the structure of cement paste have largely been applied and extended through ever maintained close contacts with prominent basic science and research abroad, in the said field above all in the USA.

the consumption. Besides, this technology is now made available for export to other countries.

Therefore, the long-term research efforts are now commencing to pay a considerable return on the investments. One should be aware that this is also due to the patient and tedious work by researchers far back in the past. They could not foresee the industrial applicability of their scientific work and could thus neither claim nor expect to be rewarded for the future economic profitability.

To some extent it is possible in retrospect to evaluate the order of magnitude of efforts and the character of research and development which has formed the basis for the now attained technology development.

Figure 16 configurates the growth of basic knowledge on the formation and structure of hardened cement paste since such research commenced at Portland Cement Association (PCA), USA, at zero knowledge in 1934 until 1975, when the basic knowledge necessary to conduct industrial processing of cement paste formation can be set at 100 per cent. The first results from PCA's efforts appeared in 1946 after 12 years' team-work by Powers et al(7), the PCA summary bulletin 22 (8) was published in 1948, "Powers' Model" was presented in 1960, Powers (9), and refined in 1965, Powers et al (10). All these comprehensive and far reaching papers were entirely exploratory.



<Figure-16> Configuration of the long-term exploratory accumulation of know-how on the hydration and structure of cement paste, originating from the commencement of basic investigations at Portland Cement Association, USA in 1934. Participation in the international exploratory research and application for winter-concreting and in the precast concrete industry took place in Denmark 1953-65. Studies for development of an industrial "hydration technology" commenced at Concrete Research Laboratory Karlstrup about 1965. Development projects were formulated 1971 - at that time about 80 per cent of the necessary basic knowledge was available, against 10 per cent of the application knowledge.

The early part of this patient accumulation of knowledge was applied in Denmark for "winter concreting" from 1953, and in the years after about 1960 also in heat curing procedures in the growing precast concrete industry.

Definitely, development oriented research aiming at recommendations and design of a "cement hydration technology" commenced in Denmark about 1965 and has also comprised exploratory research, Nepper-Christensen et al (11), Idorn(4).

It is demonstrated in Figure 16 that when the applied research to create an industrially feasible hydration technology commenced in Denmark about 1965, about 80 per cent of the necessary basic knowledge was available. This had been accumulated as shown during about 35 years' comprehensive and scattered, largely non-mission oriented research of American origin and flourished due to exceptionally intensive international exchange and cooperation after the Second World War. It is estimated (on the basis of personal knowledge through contacts regarding persons and staffs involved) that the entirety of these efforts amounts to a value of 150-200 Mill. D. kr. (1 US dol. equal to 6 Danish kroner). As for Denmark, it is estimated that the early investments in applied research, and its implementation in practice plus the return to international cooperation have amounted to about 5 Mill. D. kr. over about 15 years. The hydration technology oriented research commenced about 15 years. The hydration technology oriented research commenced about 1965, is estimated to have run into about 10 Mill. D.kr. now over 10 years. It is the latter phase of the research which is now under implementation to give its return to the investors over the forthcoming years.

The main conclusion to draw from this analysis is that new technology can be created only on the basis of a long, enduring continuity of basic research, applied research, and development investments. There has to be a coherence in this entirety of efforts. This is difficult to motivate businesswise, and also to manage, because the seeding precedes the harvest so much in time. Accordingly, it can also be seen that in order to follow up on recent research elsewhere for advancing a national development, one must possess a prolific national research environment which is concerned about both application of basic research made elsewhere, and about long-term development of the national capability in research, research management, and advance of concrete technology in practice.

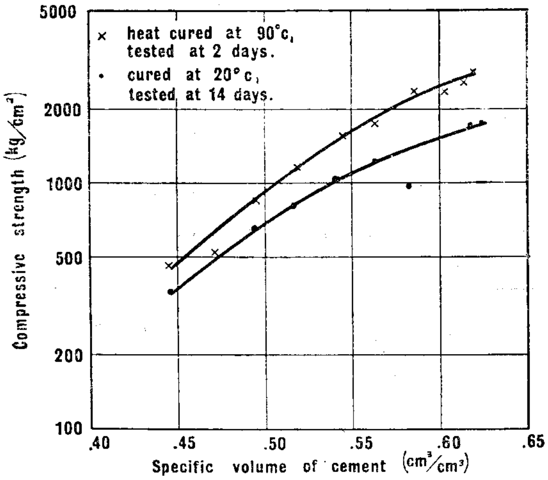
Supplementary fields of present development

The future of concrete technology is not merely to be a matter of progress with regard to cement hydration and compaction.

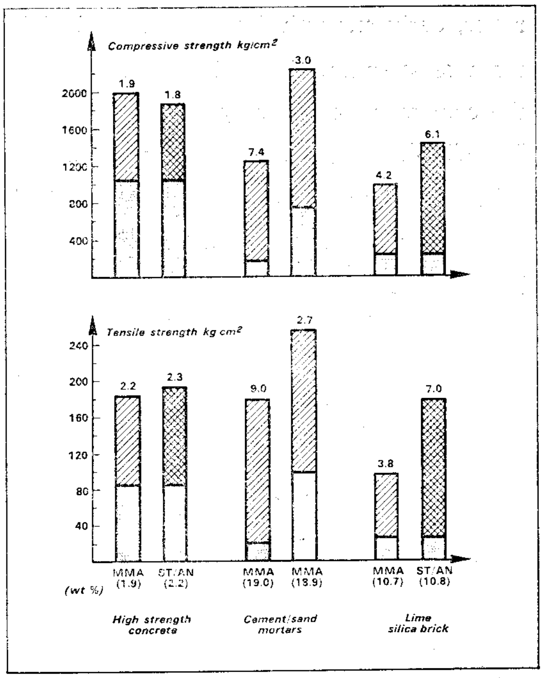
Undoubtedly, the introduction of ready-mix industry with centralized manufacture of fresh concrete does eliminate much quality variation in concrete making, but special new qualities of concrete cannot be attained this way.

This has been proved possible by means of impregnation of concrete. Various organic polymers have been found to offer concrete 2 to 6 times ordinary strength and very excellent durability. Due to the high price of organic polymers which inevitably are oil derivates there is now much research in progress concerning utilization of elementary sulphur as impregnator. Sulphur impregnation can give 2 to 3 times the ordinary strength of concrete.

Figure 17, from Idorn(4) shows that experimentally it is possible by means of effective compaction and steam curing to attain rapid strength development until almost 3,000kg/cm² of paste with finely ground fillers.



<Figure-17> Compressive strength (log scale) of Portland cement paste specimens cured at 20° Centigrade and 90° Centigrade, respectively, versus fractional cement content (by volume). The specimens were small cylinders (11.3mm high and 11.3 mm in diameter), prepared by pressing. Specific surface area of cement: 5100cm²/g Blaine. The heat cured specimens were cured under water at 90° Centigrade for approximately 24 hours; during the next 24 hours they were air dried at 90° Centigrade, cooled down to 20° Centigrade and then tested. The specimens cured at 20° Centigrade were cured under water for 7 days, dried in 65% relative humidity for 7 days, and then tested. Data from the Concrete Research Laboratory Karlstrup.



<Figure-18> Strength properties of different concrete polymer materials:
□ before impregnation;
▨ increase after impregnation with methyl
▩ metacrylate and styrene acrylonitrile. Factor of improvement over columns. From Fördös et al.

Figure 18, from Idorn(12) shows that it is possible to attain similar strength levels with polymer impregnated concrete.

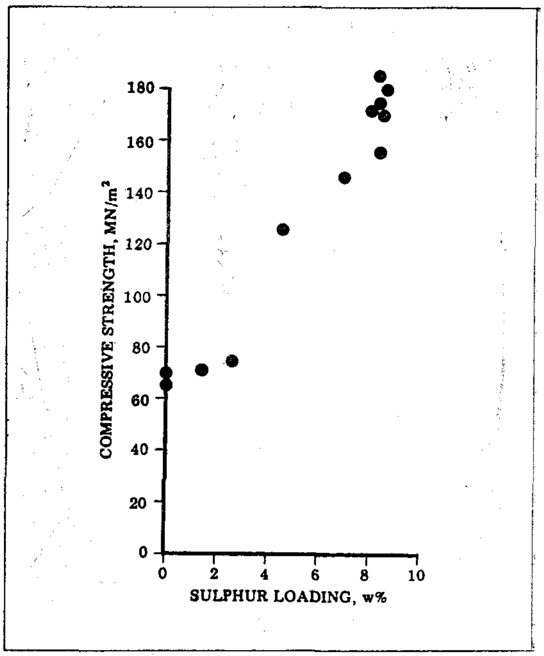
Figure 19, from Thaulow (13), shows that sulphur is also a potent impregnator.

Figure 20 summarizes the above mentioned technological possibilities and adds another one. LPC- low porosity cement—was invented in the late 60'ies by S. Brunauer. Special admixtures comprising lignosulphonates and alkali carbonates have proved able to provide high flowability at low w/c ratios, early strength development and high ultimate strength. To achieve these effects the cement must be finely ground (to about 5000-6000 Blaine) and without gypsum.

In general there is now, in the field of admixtures, an almost dramatic development in progress.

For many years—since the late 40'ies - admixtures for improvement of the frost-resistance, of retardation or acceleration of the setting and / or hardening of concrete and for improved workability, have been looked upon with somewhat mixed feelings both by cement industries and by concrete practice.

In recent years especially lignosulfonates which are derivates from the pulp industry, and synthetic products of various origin have been found able to cause remarkable reductions of the water demand in fresh concrete, also when made with ordinary



<Figure-19> Compressive strength of SIC cylinders versus sulphur loading.

TECHNOLOGY	PROPERTY	IMPROVEMENT
COMPACTION	COMPRESSIVE STRENGTH E MODULUS TENSILE STRENGTH	2 1.4 -
POLYMER IMPREGNATION	COMPRESSIVE STRENGTH E MODULUS TENSILE STRENGTH	5.5 1.7 8
SULPHUR IMPREGNATION	COMPRESSIVE STRENGTH E MODULUS TENSILE STRENGTH	3 2 -
L P C	COMPRESSIVE STRENGTH E MODULUS TENSILE STRENGTH	3 2 -

<Figure-20> Summary of improvements of concrete characteristics by compaction, polymer impregnation, sulphur impregnation and use of low porosity cements, respectively, in relation to the characteristics of ordinary concrete.

cements, simultaneously providing excellent flowability. The effects are both on the fresh concrete (less vibration, more self-induced compaction), and on the hardened (higher concrete strength per kg cement used). This field of innovation seems at present to be almost explosive, not least because the chemical industries which are partners in the development of the admixtures concerned, have powerful research capability themselves.

To go into more details on these matters requires more time and preparation than available. There would then still remain to be talked about the utilization of supplementary additives like slag, fly-ash, pozzolans etc.

Likewise, certain unpleasantries like the effect of increasing alkali and / or sulphur contents in cements ought to be mentioned, if the picture of present research and development should be made complete.

Instead of complying with such an ambitious task it is hoped that the emphasis on more special, recent Danish research and development has offered some information of interest also to progress in technology, urbanisation and industry productivity in the Far East as seen from the Far West.

It would be pleasant if this could act as seeds for further contacts in the realm of the development of cement use, and I do wish that your remarkable rate of progress in the creation of a powerful cement industry may also lead to the high efficiency in the use of cement, which we know from research that one can attain if determined efforts are invested.

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