Paper 5507.

'The Use of Aluminous Cement in the Construction of the Mosul Tunnel, Iraqi State Railways.''†

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Mr. Fred Anderson observed that the Author's experience with the use of aluminous cement concrete in the high temperatures prevailing in the Mosul area bore out to a remarkable degree statements made by Messrs. Lea and Desch on pp. 306 to 317 of their book "The Chemistry of Cement and Concrete", where, in discussing the effect of temperature on the strength of aluminous cement concrete, they stated that whilst that concrete yielded much higher strengths than Portland cement concrete when made in low (35° F.) and normal (64° F.) temperatures, it was, except at the shortest ages, considerably inferior to Portland cement concrete when made in high temperatures (95° F.). Figures were given to support that statement.

They had also pointed out that aluminous cement concretes which had suffered from the effects of too high temperatures during the hardening period showed a characteristic chocolate-to-grey colour, and it was evidently the discovery of that chocolate colour in the concrete in the south tunnel entrance at Mosul that had caused the Author so much concern and had led him to carry out his investigations. The colouring was apparently caused by oxidation of the iron compounds in the cement owing to the porous nature of the concrete.

Messrs. Lea and Desch had also stated that the critical temperature, above which aluminous cement concrete cured in water began to show a loss of strength, was around 20°–25° C. (68°–75° F.), and it was interesting to note from *Fig. 1* that the critical temperature at Mosul was apparently found to be in the region of 66° F.

It was well known that if the maximum strength of any concrete was to be developed it should be properly cured and that the most effective method of curing it was to store it in water; but it was perhaps not so well known that if the maximum strength of water-cured aluminous cement concrete was to be developed the temperature of the curing water should not be allowed to rise above 60° F.

A further point to be kept in mind when dealing with the problem of specifying a concrete which had to resist attack by sulphate-impregnated

† J. Instn Civ. Engrs, vol. 25 (1945–46), p. 142 (Dec. 1945).

waters was that the action of such chemicals was twofold: they might attack the cement or, owing to porosity of the concrete, crystal growth within the pores would have a disruptive effect. The extent to which chemical action took place depended upon the extent of surface exposed, and that again was dependent upon the degree to which the concrete was porous. In order, therefore, to achieve resistance to both chemical attack and the disruptive effect of crystal growth, it was essential that the concrete should be made as dense as possible.

Mr. F. L. Harwood observed that the Sudan Railways had used aluminous cement for certain kinds of work before the war, and fairly extensive use had been made of it in railway ashpits, where broken firebrick aggregate was used to make a refractory concrete. It had also been used in concrete work at Port Sudan to a limited extent, and the foundation of a light in the Red Sea, known as Shab Baraya light, was constructed with it in 1936.

A number of unaccountable bad failures occurred and in some cases the conclusion had been drawn that probably the specification had not been exactly followed; in particular, it was thought possible that the concrete had not been kept flooded with water for the 24 hours following its deposition. In some cases failure was complete; the concrete assumed the chocolate colour mentioned by the Author and could be picked out by hand; in other cases failure was partial.

In the case of the foundations for the light, the work was under very good supervision and the makers' specification was followed strictly; the reef on which the light was erected was just below water-level, so that the concrete had to be deposited under water, but it was mixed with fresh water. The water, together with all the other materials, was brought from Port Sudan on pontoons and the mixing, etc., was carried out on one of those craft.

There was no tide in the Red Sea, but the water-level varied during the year, the lowest level being attained during the summer months; at the time the work was carried out, the weather was very hot and humidity was high. All the materials were exposed to the sun and in their turn were heated, and the fresh water itself was doubtless at a fairly high temperature.

In due course the fact of the failure was reported to the makers and their comments were invited; they replied regretting the failure and stating that a certain proportion of aluminous cement used under tropical conditions had been discovered to behave erratically when temperatures in excess of 85° F. were *continuous* day and night. They pointed out that some very important and large-scale work had been carried out in North Africa and was thoroughly satisfactory after a period of more than 10 years, but they believed that in that case, although very high temperatures were recorded in the daytime, a considerable drop had occurred at night.

They further stated that laboratory investigations into the question had been able to reproduce a falling-off in strength under *constant* high

temperature without, however, having been able to ascertain the mechanism of the phenomena. It had been assumed that under certain conditions of hydration and temperature some change would take place in the crystalline structure of the cement, but the nature of the change and the exact conditions was even now not known. Such falling off in strength had always been accompanied by a change in the colour of the matrix, from the usual slatey-grey to chocolate.

Although no temperature records had been kept in that case, there could be no doubt that high temperature and high humidity did exist during the period in question, and probably the temperature did not fall below 85° F. during the 24 hours.

The following details of the condition of the concrete in that foundation might be of interest :—

(*a*) After 7 months : minor erosion at the water-line, not serious, and thought to be due to loss of cement during construction.

(*b*) After 17 months : a certain amount of erosion, reaching a maximum depth of 6 inches at the north-east corner.

(*c*) After 39 months : erosion in places to a depth of not more than 6 inches.

(*d*) After 45 months : cavity at the north-east corner 20 inches deep. It was reported that the concrete could be dug out freely with the bare hand and then the pieces thus secured could be rubbed adrift from the stones in the aggregate.

(*e*) After 47 months : further rapid deterioration in the 2 months since the previous report.

The light had since been dismantled and re-erected on new foundations on Abington Reef, about 3½ miles from its original position. The condition of the foundation made renewal necessary and the opportunity was taken to re-site the light in a better position.

The Author, in reply, thanked the contributors for their remarks, which, in general, confirmed the experience described in the Paper.