EVALUATION OF THE ABILITY OF MICROCRACKED CONCRETE TO SELF HEALING

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The significant role played by the microstructure of concrete in the shaping of its cracking behaviour was discussed. The possibilities of determining the autogenous healing phenomenon of microcracked concrete by means of the acoustic emission measurement were also shown. Among others, it was found that autogenous healing of compressed concrete increases both with the decrease of the initial stress level and with the increase of the period between initial loading and reloading. As well, it was proved that the capability to self healing of concrete which has lost its section continuity is comparatively unimportant.

INTRODUCTION

In general, the fracture mechanics conception accepts assumption that concrete is a homogenous material with a steady and closely determined structure formed through hydration of cement. From that point of view, in engineering practice, it is usually to assume that structure of concrete is entirely shaped after 28 days of curing. Although it is known that the hydration of cement after this period distinctly slows down nevertheless this process is going on and generates inconsiderable increment of the significant concrete mechanical properties, such as: compressive strength, tensile strength and fracture energy. The recent developments show that cracking of concrete, besides of macroscopic crack occurrence, manifests through the microcracking phenomenon, which is strongly influenced by the structure of material itself. The microcracking behaviour of concrete is mainly attributed to the formation of the structural microdefects at the contact zones between the aggregate and hardened cement matrix and also to their extension under relatively small ranges of load. These ranges are considerably lower than load levels related to the ultimate stresses in compression

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or cracking stresses in tension. Enlightenment of microcracking might be easier if the values of initial (σ_i) and critical (σ_{cr}) stresses were known (1). It was proved that initial stress corresponds with the beginning of stable propagation of microcracks. Its most probable values oscilate in the limits:

$$\sigma_i = (0.44 - 0.52)f_c$$

However, the borderline between stable and unstable microcracking progression is defined as a critical stress (σ_{cr}) which mostly range from 70 to 90 % of ultimate stress. For the concrete constructions working under the service loads the stresses reaching about 50% of the compressive strength are often tolerated. Thereby, the full exploitation of service loads or accidential overloads may cause the stable microcracking in compressed areas of concrete microstructure. If the service loads are taken down the stress level simultaneously decreases below the value of initial stress. In this moment, the problem of estimation of the ability of microcracked concrete to autogenous healing explicitly appears. It seems possible that when material is unloaded then mechanical features of concrete structure might be corrected through this phenomenon. Generally, the self healing is attributed to the hydration of previously unhydrated cement grains and may be aided by carbonization, the bonding material so formed containing crystals of calcium carbonate and calcium hydroxide. As a result, some of the tensile strength of the concrete is restored across the cracked section and the crack may become sealed. The fact that concrete has the inherent ability to heal cracks has been known since a long time (2), but not too many investigations have been carried out in this field. Among others, more interesting results were published by Hannant and Keer (3) and also by Zamorowski (4). However, this phenomenon is so far unexplored. It is obvious that getting to know the nature of the healing action, most of all depends on the development of the available methods of investigation, out of which the acoustic emission seems very promising (5). This paper presents the research concerning the application of this method to the evaluation of autogenous healing in microcracked concrete.

EXPERIMENTAL DETAILS

The basic examinations, comprising the measurement of acoustic emission in quasi-axial compression and in tensile splitting test, have been carried out on cube specimens of the dimensions 10 x 10 x 10cm prepared with concrete of 25 MPa strength. In the tests two groups of specimens have been used:

- First group of specimens was preliminary compressed at 90 days after manufacture in quasi-axial test to the selected stress levels corresponding to three different stages of concrete destruction. Then, after unloading, the specimens were reloaded to the previously obtained levels of stress. The following stress levels were assumed:

$\sigma_1 = 0.2\sigma/f_c$ - middle of the crack initiation interval
$\sigma_2 = 0.4\sigma/f_c$ - upper limit of the crack initiation interval
$\sigma_3 = 0.6\sigma/f_c$ - middle of the stable cracking interval

$\sigma_4 = 0.8\sigma/f_c$ - lower limit of the unstable cracking interval
In order to determine autogenous healing effect the period between loading and reloading was differentiated. The following values for the pauses in loading were assumed: 1 day, 2 days, 3 days, 5 days, 7 days, 14 days and 30 days. During the period of self healing the specimens were stored in climatic chamber with air temperature at 20°C and the relative humidity of 95%.

- Second group of specimens was carried out in tensile splitting test. At first, the 28 days old concrete specimens were subjected to the initial damage, consisting of a total split. Then, they were carried carefully to the water with temperature of 20°C for a period up to half a year (188 days). After the period of self healing the specimens were reloaded to the damage.

All examinations were carried out in an INSTRON universal testing machine. To measure the acoustic emission signals the equipment set made by the Acoustic Emission Technology Corporation (USA) and Polish equipment "EA-3" were used. The acoustic emission parameters have been independently recorded using microcomputer IBM and two-channel graphic recorder, made by Riken Denshi from Japan. The friction between the specimen and the surface of the loading beam was eliminated by polishing the specimens surfaces and greasing them with grease STP. The load has been applied perpendicularly to the setting direction. All tests were carried out at 20°C temperature and relative humidity of 54%.

RESULTS

The results obtained have shown that it is possible to determine the autogenous healing effect by means of the acoustic emission measurements. For instance, Fig.1 and 2 show the total acoustic emission counts recorded during initial loading and reloading, after healing period, up to the stress levels which correspond to 20 and 60 % of ultimate stress, respectively. In both figures the total AE counts were plotted against the stress as percent of the ultimate stress. The results obtained have shown that the measurement of acoustic emission permits to determine the extent of autogenous healing of plain concrete. It can be seen that as the duration of healing period increases the total number of AE counts also increases. It is caused by the fact that a considerable influence of the healing effect appeared here. Basing on this purpose the coefficient "S" was postulated as an evaluating criterion, which was defined as the degree of self healing effect.

$$S = \sum AE_R / \sum AE_I \times 100\%$$

where: $\sum AE_R$ - total AE counts, recorded during reloading
$\sum AE_I$ - total AE counts, recorded during initial loading.

The obtained values of this coefficient for the various levels of initial stress and differentiated healing periods have been shown in Fig.3. It may be observed that when the initial stress level is rather small and when the period between loading and reloading increases then there is a distinct tendency to a considerable autogenous healing of the concrete microstructure. For higher values of primary loading the capability of this phenomenon significantly decreases.

Quite different results have been obtained from examination of the capability to self healing of concrete which has lost its section continuity. For example in Fig.4 the re-cracking tensile splitting strength of the "healed" specimens were compared with the results obtained from uncracked control samples curing in the same conditions.

To carry out the analysis of autogenous healing phenomenon in total split concrete specimens the following parameters have been postulated:

$$\alpha = f^{H}_{cts}/f^{216}_{cts} \times 100\% \qquad \beta = f^{H}_{cts}/\Delta f_{cts} \times 100\%$$

where: α - degree of the tensile splitting strength recovery
β - relative degree of the tensile splitting strength recovery
f^{H}_{cts} - re-cracking tensile splitting strength
f^{216}_{cts} - tensile splitting strength determined after 216 days of curing from uncracked control samples
Δf_{cts} - increment of the tensile splitting strength obtained in healing period from uncracked control samples

$$\Delta f_{cts} = f^{216}_{cts} - f^{28}_{cts}$$

where: f^{28}_{cts} - tensile splitting strength corresponds to total split obtained 28 days after manufacture.

Basing on the obtained results of the acoustic emission measurements the similar evaluating criterions have been defined as follows:

$$\alpha_{AE} = \sum^{H} AE / \sum^{216} AE \times 100\% \qquad \beta_{AE} = \sum^{H} AE / \Delta \sum AE \times 100\%$$

where: α_{AE} - degree of the acoustic emission recovery
β_{AE} - relative degree of the acoustic emission recovery
$\sum^{H} AE$ - total AE counts recorded during reloading
$\sum^{216} AE$ - total AE counts recorded during tests of uncracked control samples after 216 days of curing
$\Delta \sum AE$ - increment of the AE counts recorded during tests of the uncracked control samples after a period of healing.

$$\Delta \sum AE = \sum^{216} AE - \sum^{28} AE$$

where: $\sum^{28} AE$ - total AE counts recorded during initial damage 28 days after manufacture.

The following values of the assumed evaluating criterions have been obtained:

$$\alpha = 6\% \approx \alpha_{AE} = 8\% \qquad \beta = 82\% \approx \beta_{AE} = 78\%$$

It may be observed, in comparison with the microcracked concrete, that the capability to self healing of concrete which has lost its section continuity is rather small.

CONCLUSIONS

1. It was proved that acoustic emission measurements permit to determine the range of autogenous healing phenomenon of plain concrete.
2. The capability to healing action of microcracked structure of concrete increases both with the decrease of the initial stress level and with the increase of the duration of healing period.
3. The capability to healing cracks in concrete which has lost its section continuity is comparatively unimportant.

SYMBOLS USED

f_c - ultimate compressive strength (MPa)
f_{cts} - ultimate tensile splitting strength (MPa)
σ_i - initial stress (MPa)
σ_{cr} - critical stress (MPa)
S - degree of self healing effect (%)
α - degree of the tensile splitting strength recovery (%)
β - relative degree of the tensile splitting strength recovery (%)
α_{AE} - degree of the acoustic emission recovery (%)
β_{AE} - relative degree of the acoustic emission recovery (%)

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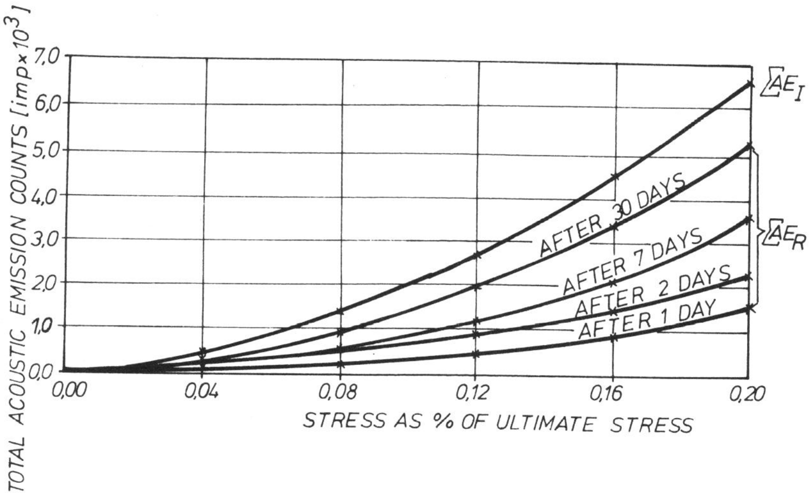

Figure 1 Influence of the duration of healing period for stress level corresponding to 20% of ultimate stress

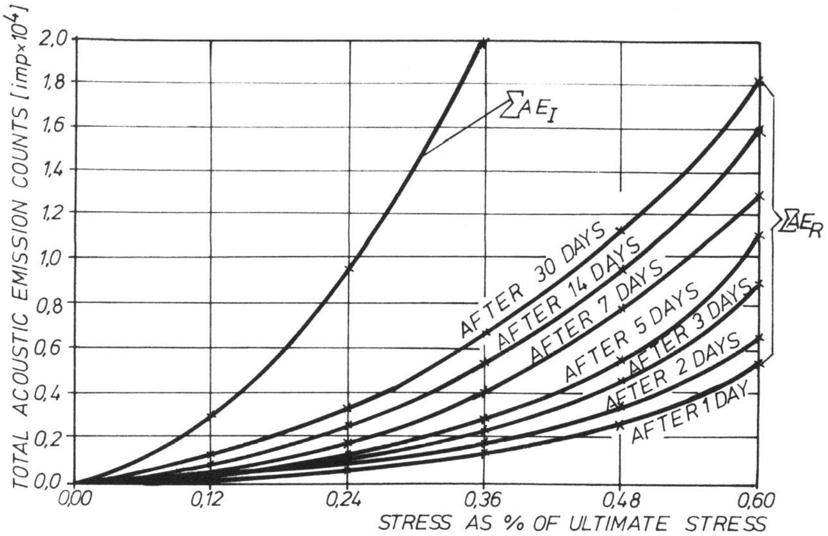

Figure 2 Influence of the duration of healing period for stress level corresponding to 60% of ultimate stress

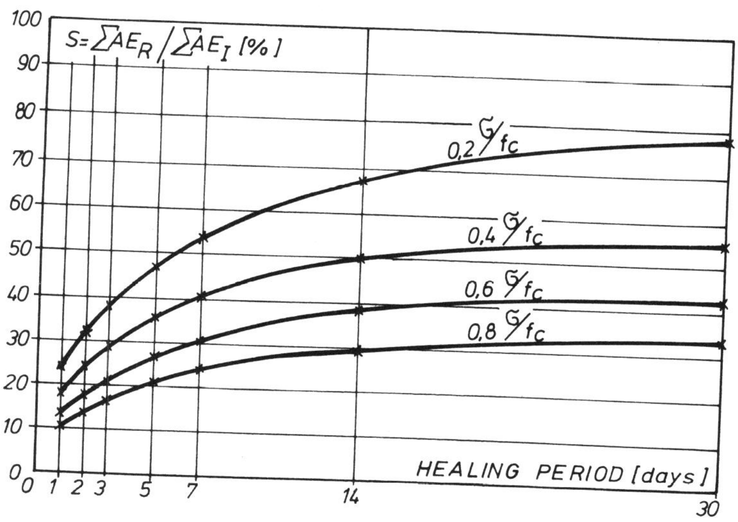

Figure 3 Degree of self healing effect for the various levels of initial stress

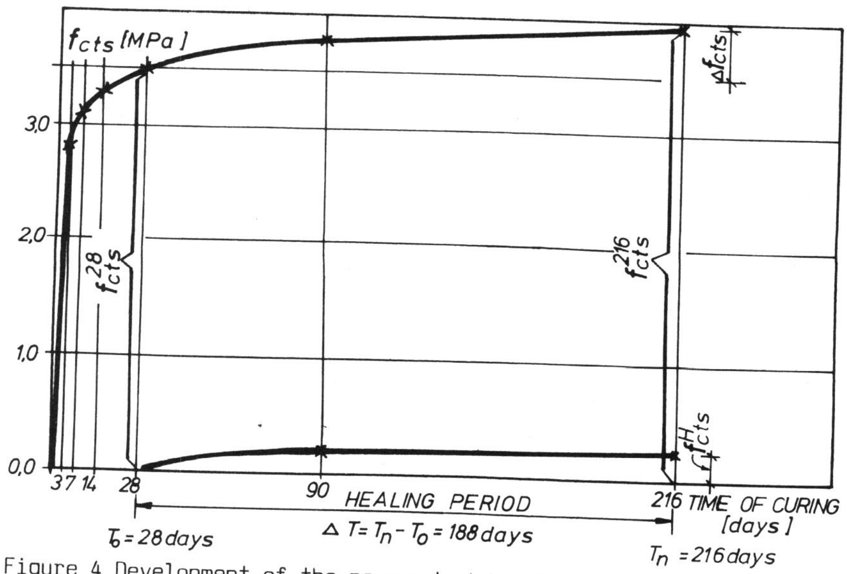

Figure 4 Development of the re-cracked tensile splitting strength compared with the uncracked one.