

Fracture characteristics of cold jointed concrete identified by acoustic emission technique

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ABSTRACT: Sequence and quality of concreting are important factors effecting strength of the concrete members. Since casting the whole structure monolithically is very difficult, delayed concreting causes cold joints which are the weak transition zones between two different concrete layers. Cold joints have serious consequences particularly at columns, beams and column-beam joints. A large number of studies can be found in the literature mentioning about detrimental effects of cold joint and prevention of it. However, identifying fracture mechanism of this zone is still an under-researched subject.

In this study, revealing fracture characteristics of cold-jointed concrete was aimed. For this purpose, acoustic emission (AE) monitoring, which is a developed nondestructive testing method, was performed experimentally. A reference monolithic and a cold-jointed concrete beam specimens were produced in the laboratory and were tested under bending. Besides mechanical features, invisible fracture characteristics were also identified and influences of cold joint were determined. Much higher AE energy releasing was observed in cold-jointed specimen at fracture instant. In addition, damage scales of cold-jointed specimen were approximately 64 times larger.

Keywords: cold joint, concrete, acoustic emission (AE), flexure.

1 INTRODUCTION

It is difficult to cast the entire structure monolithically or casting cannot be completed in one time in reinforced concrete structures. Also, there can be a delay in transportation of concrete from ready mix concrete plant to site location. Joints are the interface of materials with different mechanical properties and contents. For this reason, stress concentrations occur in these regions and the strength and load transfer capacity decrease. Therefore, the behavior of the structure is highly dependent on the bond quality of this concrete-concrete interface. Characteristics of the concrete-concrete interface are influenced by many factors such as degree of roughness, angle, bond strength, water content of the joint, shrinkage and strength parameters.

Researches on the bond strength of concrete-concrete interfaces started in the 1960s. The most important contribution in this context is "shear-friction theory" proposed by Birkeland and Birkeland (1966). Rao and Kishen (1993) studied the effect of the concrete member size on effects of cold joint under flexure. The results show that, as the size of the sample increases, the maximum load-bearing capacity rises and the flexural strength of the cold-jointed concrete decreases. Kadyrov and Yazıcıoğlu (2016) prepared cylindrical and prism specimens and formed cold joints with 45 and 90 degree angles. They analyzed the effect of cold joint on tensile strength under bending and splitting. The cold joint was created by waiting for 2, 3, 4 and 6 hours after pouring the first half of the samples. As a result of the experiments, it was



observed that the bending and direct tensile strengths decrease as the period of cold joint formation increases. It was determined that, this decrease was more pronounced in the concrete poured after 6 hours. In addition, the 45 degree angled samples exhibited higher strengths. A large number of studies can be found in the literature mentioning about detrimental effects of concrete-concrete interface and prevention of it. However, limited studies were conducted on examination of cold jointed zone by AE: Shah and Chandra Kishen (2010) investigated the shear-fracture behavior of the cold joint on concrete elements having different sizes and strengths under bending by using AE method. The data obtained show that, with rising in the difference between the compressive strength of the concrete on both sides of the interface; the load-bearing capacity of the beams, the number of AE events, AE energy, widths of the fracture and damage zones reduce. While a few studies have been conducted on cold-jointed concrete under shear, AE characteristics of cold-jointed concrete under bending have not been investigated yet. For this reason, in this study, revealing fracture characteristics of cold-jointed concrete was aimed. A reference monolithic and cold-jointed concrete beam specimens were produced in the laboratory and were tested under bending. AE monitoring was conducted simultaneously with the loading. Beside mechanical features, invisible fracture characteristics were also identified and influence of cold joint was determined.

2 ACOUSTIC EMISSION (AE) TECHNIQUE

Acoustic emission (AE) is defined as release of energy and propagation of it as elastic waves in a stressed material due to fracture (ASTM E 1316). The method is based on detection of these waves by appropriate sensors. By analyzing these wave signals, location, type, orientation and origin time of various damages in different materials can be determined. For this purpose, AE signal parameters given in Figure 1 are used to evaluate AE activities. Generally used AE parameters are amplitude, average frequency, energy, duration, rise time and count. Besides, in order to consider only meaningful signals apart from the noises, a “threshold” is set.

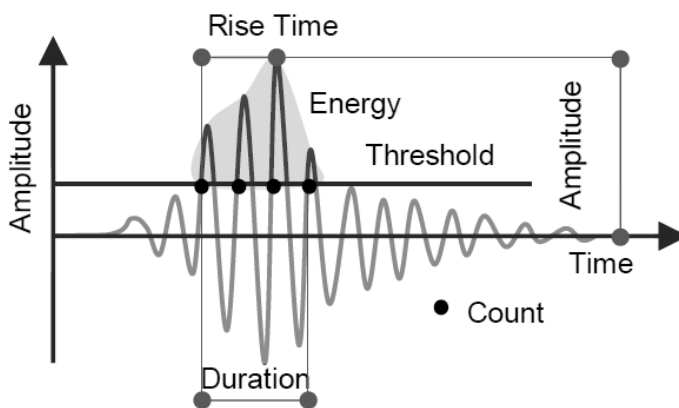


Figure 1. AE signal parameters.

3 EXPERIMENTAL STUDY

3.1 Materials

For the experimental study two 10x10x60 cm monolithic and cold-jointed beam specimens were prepared according to the TS EN 12390-5 standard. The preparation procedure is depicted in Figure 2. Considering initial setting time, concrete was prepared with the time laps of 6 hours. Interface was designed in the middle of the beam and angle between cold joint and bending force direction was 0 degree.

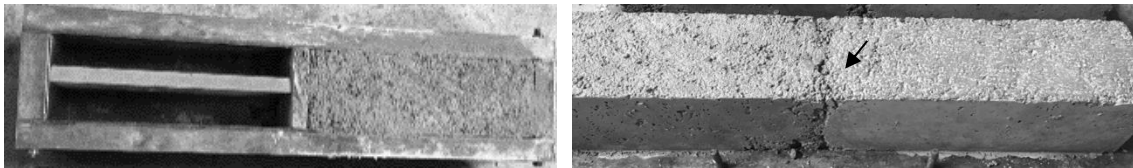


Figure 2. Production of the cold jointed specimen

CEM I 42.5R cement and crushed limestone aggregates were used in concrete mix design as given in Table 1. Water/cement ratio of the mixture was 0.63. 28-day compressive strength of concrete was 30 MPa. Four-point-bending tests were conducted at the end of 28 days curing.

Table 1. Mix design of concrete (kg/m³).

Material	Cement	Water	Aggregate			Superplasticizer
			0-5 mm	5-12 mm	12-22 mm	
Amount	260	164	1057	431	451	1.94

3.2 Test setup

Four-point-bending loading was monotonic and displacement controlled with a speed of 0.2 mm/min. Load setup and dimensions of the specimens are shown in Figure 3. To determine fracture characteristics by AE, 6 AE sensors with resonant frequency of 150 kHz were attached to specimens (Figure 3). AE signals were amplified with pre-amplifiers having gain of 40 dB. Load and displacement values were also recorded simultaneously.

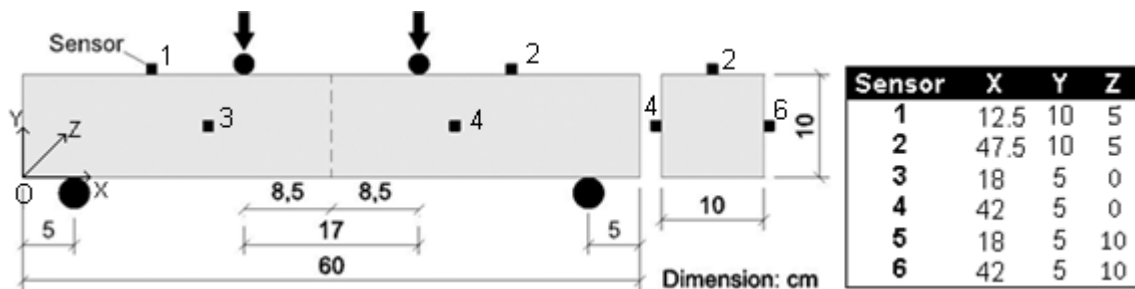


Figure 3. Four-point-bending setup and AE sensor locations

4 RESULTS

4.1 Mechanical results

Load vs. deflection behaviors of the specimens under four-point-bending loading are presented in Figure 4. As seen from Table 2, while maximum load capacity of monolithic specimen was 9506 N, this value decreased 48% for the cold-jointed specimen and it could resist only up to 4522 N load level. In addition, whereas maximum deflection was measured as 2.281 mm for monolithic specimen, cold-jointed specimen failed at 0.806 mm deflection level where load dropped. Thus, with the presence of cold joint, toughness and ductility of the beam were negatively affected and the specimen failed much more suddenly. Failure states of the specimens are presented in Figure 5.

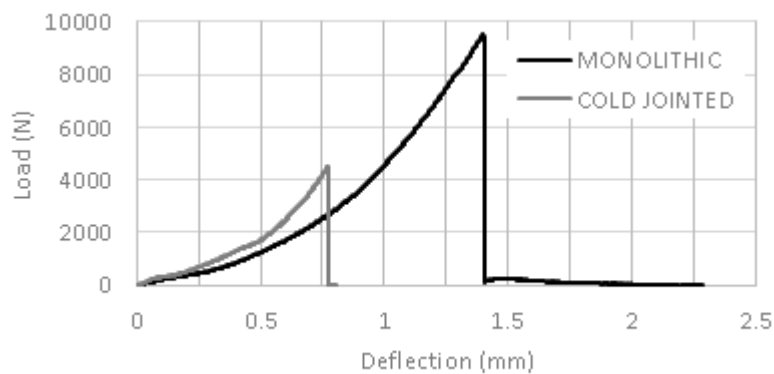


Figure 4. Load vs. deflection curves of the test specimens.

Table 2. Mechanical results of the test specimens.

Test specimen	Ultimate load capacity (N)	Maximum deflection (mm)	Toughness (N-mm)	Ductility
MONOLITHIC	9506	2.281	8906	1.48
COLD-JOINTED	4522	0.776	2383	-

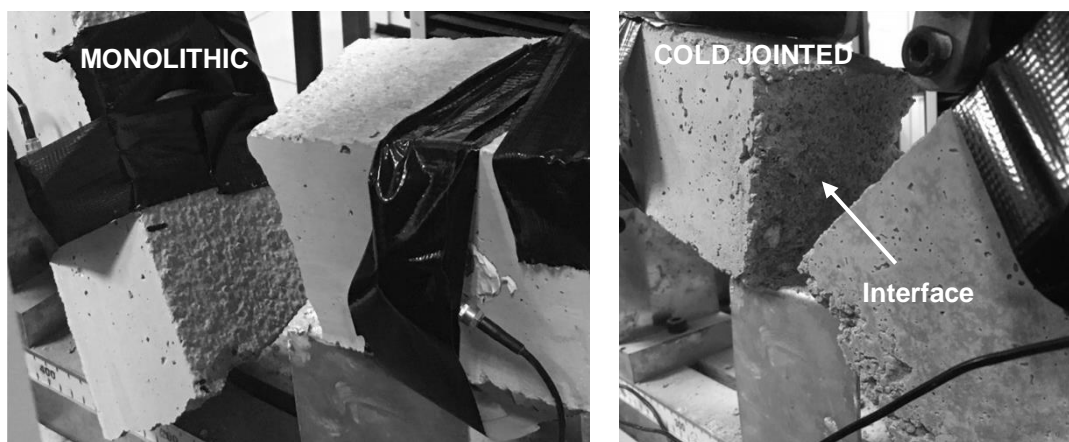


Figure 5. Failure states of the specimens.

4.2 AE results

In total 1679 and 452 AE hits were recorded during the test of monolithic specimen and cold-jointed specimen, respectively. As seen from Figure 6, AE activities of both specimens started to originate at early load levels. Amplitude values of these activities were lower. As the load increased and the beams damaged, number of AE hits having higher amplitude values increased. However, a distinguishing feature occurred at the load drop moment: After the load dropped, while monolithic specimen continued to deflect, cold jointed specimen immediately fractured. For this reason, 7% of AE activities of monolithic specimen were observed at load drop moment, however 77% of them originated at failure at 2.281 mm deflection level. In contrast, 70% of AE activities in cold-jointed specimen were observed at 0.776 mm deflection level.

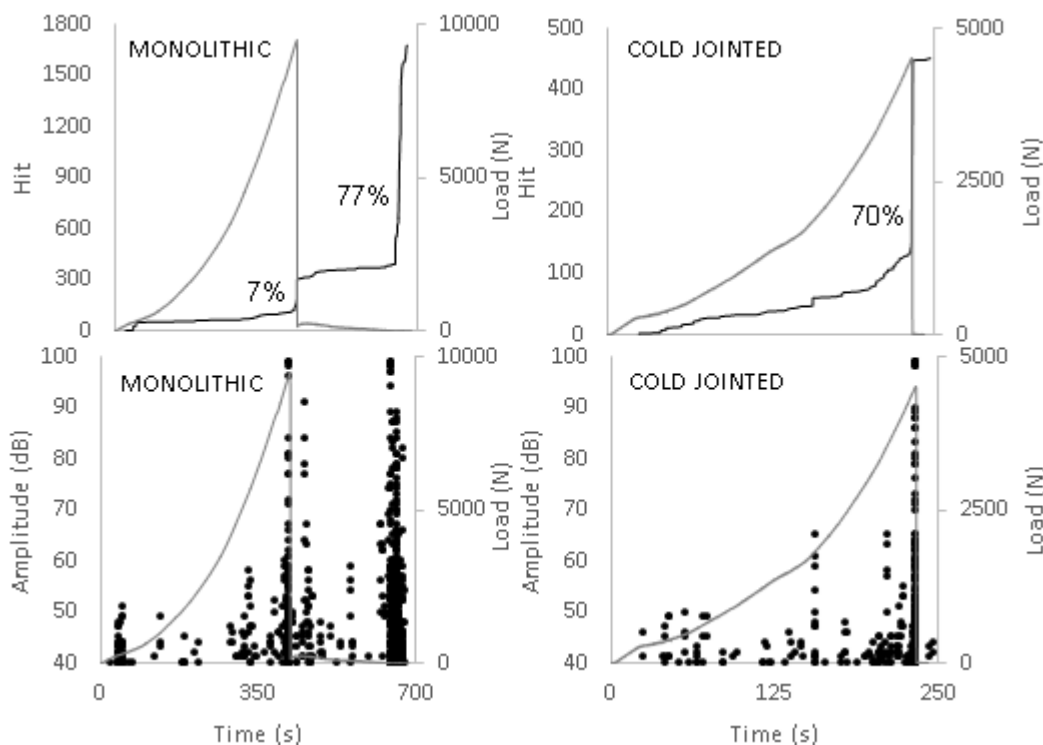


Figure 6. Hit and amplitude variations of the specimens (Black: hit, grey line: load).

Total 505679 aJ and 446197 aJ AE energies were released in monolithic specimen and cold-jointed specimen, respectively. This value for cold-jointed specimen might seem lower. However, this is a dramatic energy release for such a short-time test and lower load and deflection levels. As seen from Figure 7, similar behavior to hit variations was also seen in energy variations. While maximum energy of AE hit was approximately 39608 aJ at load drop moment, maximum 57885 aJ was released when the monolithic specimen fractured. However, 65535 aJ, which was the energy limit that the AE system can record, was obtained at load drop of cold-jointed specimen. Accordingly, 24% of total AE energy of monolithic specimen was observed at load drop moment; however 74% of them originated at failure at 2.281 mm deflection level. In contrast, 99% of AE activities in cold-jointed specimen were observed at 0.776 mm deflection level. This state also indicates effect of cold joint on fracture scale: An energy discharge is encountered before fracture in the monolithic specimen. However, presence

of cold joint prevents this behavior and very large energy release at once was observed due to large-scale fracture.

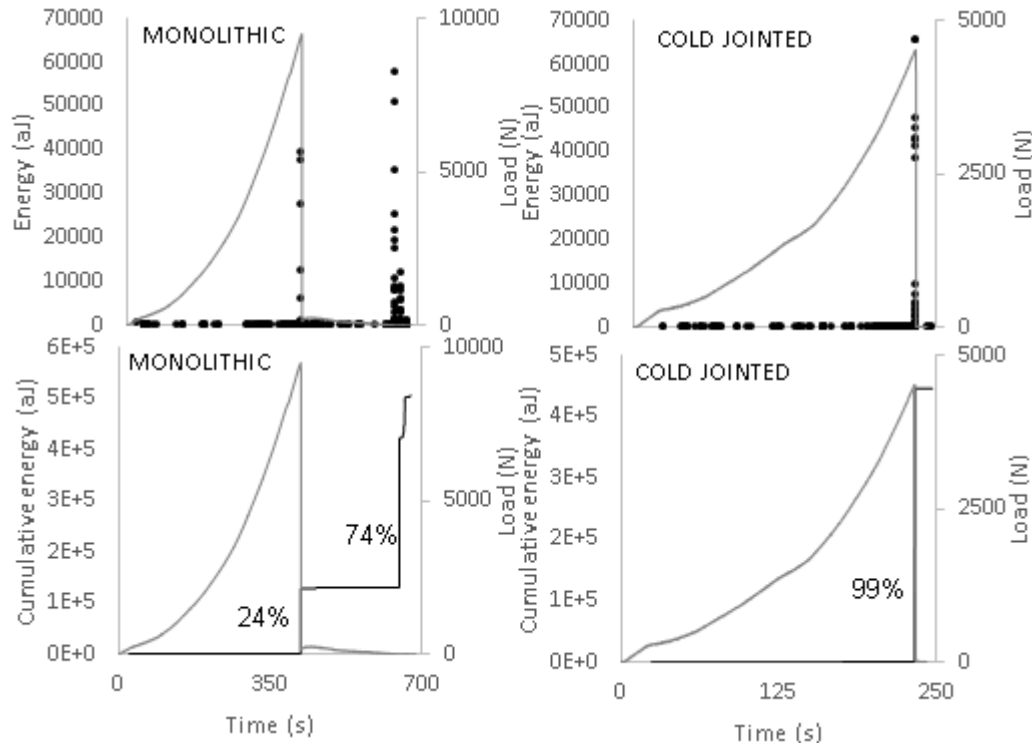


Figure 7. Energy variations of the specimens (Black: energy, grey line: load).

RA-value vs. average frequency distributions of the specimens were also obtained according to JCMS-III B5706 (2003). These parameters are used to distinguish the type of a crack. As seen from Figure 8, RA-values of the cold-jointed specimen are lower. As higher RA-values and lower average frequencies can be characterized as shear-type, this could be attributed to presence of higher tensile stresses in cold joint region.

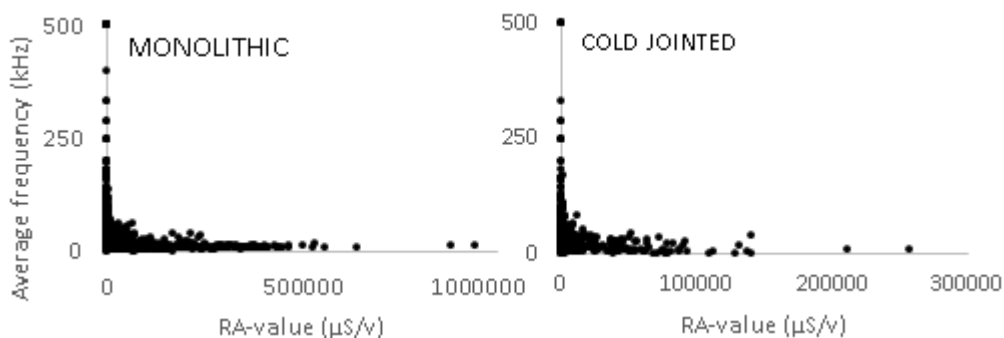


Figure 8. RA-value vs. average frequency variations of the specimens.

Figure 9 presents Ib-value variations of the specimens with respect to deflection. Ib-value parameter is used for scaling AE activities by using Equation 1 for certain groups of amplitude parameters.

$$Ib\text{-value} = 20 \frac{\log_{10} N_1 - \log_{10} N_2}{a_2 - a_1} \quad (1)$$

where N_1 indicates the number of maximum amplitude values (a_1) less than difference between mean and standard deviation of the amplitude distribution. N_2 also indicates the number of minimum amplitude values (a_2) higher than difference between mean and standard deviation of the amplitude distribution. Thus, lower Ib-values indicate large-scale damages.

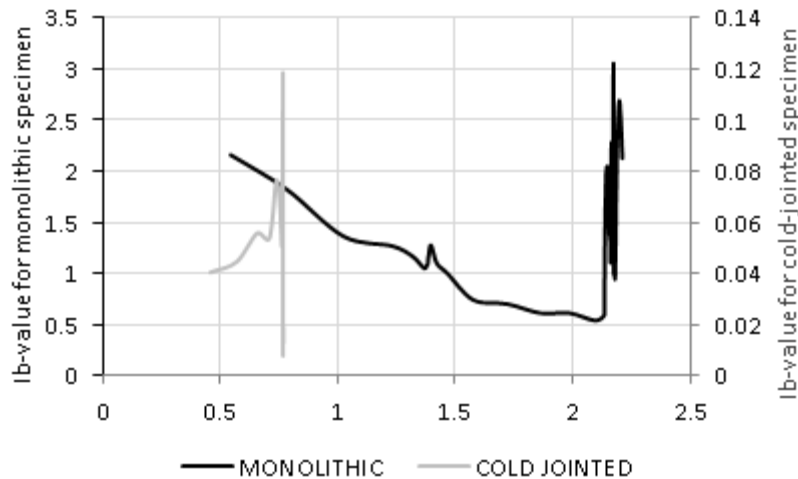


Figure 9. Ib-value variations of the specimens with respect to deflection.

While Ib-values of monolithic specimen were in a downward trend until the load dropped, an opposite behavior was faced in the cold-jointed specimen. In other words, larger-scale damages were observed in low load levels of monolithic specimen; thus, final fracture was weakened. Moreover, Ib-values of cold-jointed specimen were lower than those of monolithic one. Hence, damages in this specimen were larger-scale. While minimum Ib-value of monolithic specimen was 0.58, that of the cold-jointed specimen was 0.009. It can be roughly said that 64 times larger-scale damages developed due to presence of cold joint.

5 CONCLUSIONS

This paper focuses on identifying fracture characteristics of cold-jointed concrete under fracture. For this purpose, a monolithic and a cold-jointed concrete beam specimens were tested under four-point-bending and were simultaneously monitored with AE. Consequently, following conclusions were obtained from the study: Maximum load and deflection capacities, toughness and ductility of concrete beam decreased and a sudden fracture occurred with presence of cold joint. Although less AE activities were recorded in cold-jointed specimen, their energies were higher even at low deflection levels. While 74% of total AE energy was released at fracture instant of monolithic specimen, this percentage increased up to 99% and a much larger energy releasing was observed in cold-jointed specimen. The presence of cold joint decreased RA-values due to higher tensile stress concentrations in cold joint region. Ib-value also demonstrated that damage scales of cold-jointed specimen were approximately 64 times larger compared with the reference specimen.

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