ABSTRACT

Rocks when subjected to stress undergo microcracking. With further increase of stress microcracks extend interact and coalesce to form a macroscopic crack. Each of these phases or stages of the cracking phenomena is influenced by stress, temperature, time, humidity, mineralogy, microstructure, and macroscopic geological discontinuities. Further, it is well established that with the increase of stress, new cracks form, they interact and coalesce forming macroscopic cracks. A survey of the existing open literature does not indicate any significant study relating strain rate and thermal exposure effects to the generation of new cracks and their growth in phases. Thus this aspect which is very important from the safety viewpoint of underground structures, has been undertaken as the main theme of the present thesis. Specific investigations were carried out on granites at normal strain rates of 10^{-5}, 10^{-6} and 10^{-7} (per second) and at temperatures of 28°C (room temperature), 200°C and 400°C and are reported. And, Ultrasonic imaging and Acoustic Emission have been used as the key tools to study the various stages of microcracking phenomena. The work carried out under the defined scope is presented in chapters 4 to 9, while a brief introduction to the cracking phenomenon in rocks and to the two techniques is included in the first chapter, the strain rate dependence and thermal exposure effects on deformation and strength are investigated in the second chapter.

Ultrasonic imaging of rocks under stress which is presented in chapter 3 reveals the occurrence of micro and macro crack damage. The images obtained are identified and termed as i) microcrack damage designated as types A, B, C & D, ii) macrocrack damage termed as type E. With the increase of stress there is a transformation from one type of damage into the other occurring in sequence A → B → C → D → E. In the subsequent chapters the results obtained from Ultrasonic imaging and Acoustic Emission are presented and discussed in detail. The highlights of these results are summarised in the following.

Acoustic Emissions were monitored during the uniaxial compression testing. Based on the parametric analysis, AE events are classified into micro and macrocrack phases:

- **Microcrack phase**: α (44-60 db) and β (61-70 db)
- **Macrocrack phase**: γ (71-80 db) and δ (81-100 db)
With the decrease of strain rate compressive strength decreases and Young's modulus is found to be independent of strain rate. For a given stress the inelastic strain is higher lower the strain rate. Since the inelastic strain is directly related to microcrack development, it can be inferred that with the decrease of strain rate microcracking activity increases. Ultrasonic images showed damage in the form of clusters. Microcrack damage increases with the increase of stress and also with the decrease of strain rate. Cluster growth forming a network and critical damage affecting both the deformation and strength occurs at lower stress levels with the decrease of strain rate. Acoustic Emission monitoring shows cumulative damage and microcracking rate increases with the decrease of strain rate. Maximum microcracking activity was recorded prior to failure. Micro and macrocracks are initiated at different stress levels, the crack initiation stress for microcrack phase decreases with the decrease of strain rate, but the macrocrack phase initiation is at the same stress level irrespective of strain rate. It implies that localized macrocrack nucleation and their extension occur at the same stress level irrespective of strain rate. With the decrease of strain rate, there is an increase in the microcrack phase. A large increase in population of the microcrack phase results in a distributed macrocrack nucleation. Based on these inferences, it can be concluded that early occurrence of damage and distributed initiation of macrocracks are responsible for the decrease of failure strength with the decrease in strain rate.

The compressive strength of a 200°C treated sample shows the highest strength value compared to the unheated and 400°C treated sample. The strength of a 400°C treated sample is more or less comparable to the strength of an unheated granite. Ultrasonic images for unheated and thermally treated samples show that microcrack damage increases with thermal treatment. When thermally treated samples are stressed, the growth of microcrack damage shows anomalous behaviour. Thermal treatment increases microcrack damage, but when subjected to stress it indicates a lesser increase in damage as compared to unheated samples. In the case of 200°C treated sample thermal treatment retards the initiation of stress induced microcracks but in the case of 400°C treated sample prevents the early coalescence of clusters. This shows that thermal treatment toughens the rock material. Toughening depends on the thermal crack density which is evident from the behavior of 200°C and 400°C treated samples.
Acoustic Emission monitoring indicates that in the case of 200°C thermally treated sample a higher stress is required for the generation of events. And, the Amplitude distribution shows that in the case of thermally treated samples, with the increase of stress a larger number of microcrack events and smaller number of macrocrack events are produced. Based on parametric analysis, events are classified into micro and macrocrack phases. The microcrack events are termed as $\alpha$ and $\beta$ whereas macrocrack events are termed as $\gamma$ and their extension as $\delta$. In the case of 200°C thermally treated sample, micro ($\beta$) and macrocrack ($\gamma$ and $\delta$) events are initiated at a higher stress level compared to unheated and 400°C treated sample. In the case of 400°C treated sample, although the microcrack damage is high due to thermal treatment, the nucleation of both micro and macrocracks occurs at the same stress level, which is similar to the behaviour of an unheated sample.

Further both Ultrasonic images and Acoustic Emission monitoring show that for thermally treated samples the micro and macrocrack nucleation are delayed, which indicates that the thermal treatment resists the nucleation of cracking and toughens the rock material. Toughening arises due to the generation and opening of microcracks. Opening of cracks induces compressive stresses on the crack faces there by increasing the resistance for crack propagation. And, toughening and degradation mechanisms depending on the orientation density and spacing of microcracks operate while, degradation corresponds to the coalescence of microcracks leading to the formation of a macroscopic crack. With the increase of damage, microcracks initially provide toughening and, further when the crack density increases both crack coalescence and toughening occur. Finally, when microcracks are very close to each other, only crack coalescence occurs and the degradation mechanism predominates.

Uniaxial compression tests on unheated and thermally treated granite samples have clearly established the dual role of microcracks, which operate in the toughening and degradation mechanisms. In the process of thermal treatment, an increase in microcrack damage brings about toughening, which reaches a maximum value at 200°C, beyond which it decreases. At 400°C both toughening and degradation occur more or less equally and at 600°C only degradation is observed.

Thus, through this thesis an understanding into the phenomenon of microcracking which plays a very important role, in relation to strain rate and thermal exposure has been achieved using Ultrasonic imaging and Acoustic Emission.