CREEP BEHAVIOR OF ROCK

a thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

In

Mining Engineering

By

MANAS RANJAN BHOI

108MN028

Department of Mining Engineering

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Under the Guidance of

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CERTIFICATE

This is to certify that the thesis entitled **"***CREEP BEHAVIOR OF ROCK***"** submitted by Sri Manas Ranjan Bhoi, Roll no. 108MN028 in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date: (**Dr. MANOJ KUMAR MISHRA**)

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CONTENTS

ABSTRACT

Mining activities of minerals play a very important role on the health and wealth of any nation. Though technology has reduced the adverse effects to a great extent, it is still experiencing unpredictable behavior of rocks. The physical and mechanical properties of rocks are important design parameters of any excavation process. The consideration of time dependence is essential for the study of deformation and fracturing processes of rock material, especially for those subjected to strong compressive and tensile stresses. In this study creep test is conducted in chromite ore under uniaxial compressive stresses. The behavior of rock is investigated as well as strength of rock. Creep behavior of rocks has been evaluated at varying stress and temperature rate. The relationship between compressive stress and time under uniaxial compression has also been developed. Finally nonlinear creep model is used to describe the creep behaviors of rocks under uniaxial compressive strength

CHAPTER 01

1.**INTRODUCTION**

1.1 Introduction:-

In the recent years civilization has increased and so the modern amenities in the form of minerals and power. To fulfill this requirement by the people mining has also increased. Mining produces both power and minerals to the society. Mainly two types of rock are being excavated namely coal and non-coal (mineral). Which can be categorize as soft rock and hard rock. Coal is soft rock where as minerals are hard rock. Due to mining changes in dynamic force ad temperature takes place underneath the earth crust.

To characterize rock behavior for engineering purposes, elasto-plastic models are usually considered thus neglecting the time influence on the deformation mechanisms and rock strength level. Even if viscous effects are not significant when compared to elasto plastic effects in usual laboratory testing, disregarding these effects could lead to large discrepancies between pre-directed data and real field measurements. For instance when considering deep excavations in rocks, such as large section tunnels or drilling bore holes, neglecting time effects may lead to incorrect evaluation of deformations at the walls and thus impact on the criteria for selection of the proper design.

An even more interesting case is related to the compaction of hydrocarbon reservoirs and the induced land subsidence, where surface deformations are either underestimated. In the case of the Ekofisk oil field, where subsidence has reached 6m, several modifications were needed to estimate correctly the subsidence amount. On the other hand there are compacting fields in normally consolidated basins whose overlying strata behave in a more rigid way with respect to the model prediction.

In these cases, if time effects have been considered, generally they are linked to the consolidation effects due to the increase of effective stresses. But creep effects that are due to the presence of stationary load are not accounted for, even if they may contribute to modify the rock behavior by reducing the yield stress and strength level.

The macroscopic stress strain time behavior resulting from these tests can be described using rheological models, which consist of a combination of elements such as springs, plastic sliders and dashpots that emulate the basics features of the material behavior .placing elements in series and / or parallel and by varying their characteristics, the rheological models help to give a better understanding of the visco-elastics and elsto – viscoplastics behavior. However, these models have deficiency, because they do not account for shear and normal stress, temperature and intrinsic structure. Phenomenological laws, based on physical processes can be developed to characterize rock behavior under more general stress, strain and time conditions.

In the last decades, many experimental and theoretical studies have been devoted to describe the viscous behavior of low porosity rocks and rock salt.

1.2 Aim and objectives of the Study;

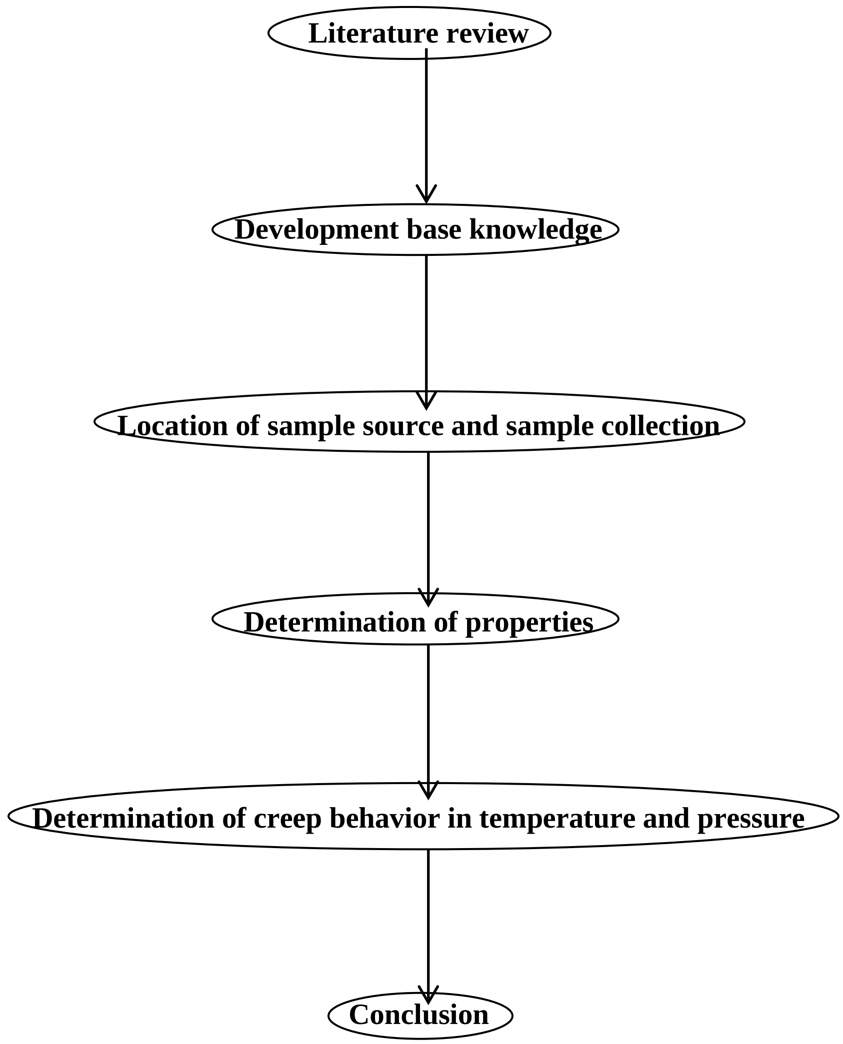
The goal of the investigation is to evaluate the mechanical properties of rock under various conditions. The specific objectives adopted to achieve the goal are following:

- To critically review the literature to understand different aspects of rock and its behavior
- To determine the mechanical properties of rocks at various temperature and pressure

1.4 Methodology:-

The objectives mentioned above could only be accomplished if worked in a plan approach. The first step towards an ambition always starts with exploring everything about it. Hence I began with the literature review. In this regard the books, journals, papers proved to be a rich source of knowledge and were thoroughly studied and learned.

This was followed by collection of sample from the local mine. Samples from many sample points were collected and carefully packed hermetically in a vibration proof box and sent to the laboratory for the analysis. After the sample collection the samples were prepared for laboratory testing. Results were found out from the experiment an then creep behavior is analyzed. Conclusions were drawn from the results and analysis. The following flow chart describe details about the methodology



Chapter 02

LITERATURE REVIEW

2.1 ROCK

Rock is a naturally occurring solid aggregate of minerals . The Earth's outer solid layer, the lithosphere, is made of rock. In general, rocks are of three types, namely igneous, sedimentary, and metamorphic. The scientific study of rocks is called petrology, and petrology is an essential component of geology.

2.2 MINING

Mining is the extraction of valuable minerals or other geological materials from the earth, from an ore body, vein or (coal) seam. This term also includes the removal of soil. Materials recovered by mining include base metals, precious metals, iron, uranium, coal, diamonds, limestone, oil shale, rock salt and potash. Mining is required to obtain any material that cannot be grown through agricultural processes, or created artificially in a laboratory or factory. Mining in a wider sense comprises extraction of any non-renewable resource (e.g., petroleum, natural gas, or even water).

Figure1. mining operation

Mining of stone and metal has been done since pre-historic times. Modern mining processes involve prospecting for ore bodies, analysis of the profit potential of a proposed mine, extraction of the desired materials and finally reclamation of the land to prepare it for other uses once the mine is closed.

The nature of mining processes creates a potential negative impact on the environment both during the mining operations and for years after the mine is closed. This impact has led to most of the world's nations adopting regulations to moderate the negative effects of mining operations. Safety has long been a concern as well, though modern practices have improved safety in mines significantly.

2.3 CREEP

Creep refers to the time-dependent deformation of soil or rock resulting from internal rearrangement of particles in response to the application of a sustained stress difference = (σ_1-σ_3)generally smaller than the stress difference of the soil at failure =(σ_1-σ_3)$_f$ where σ_1, σ_3 are the major and minor compressive principal stresses, respectively. Deformation during undrained creep results from shape distortion as the soil mobilizes a constant shearing resistance in response to the shear stresses applied upon loading or unloading. Creep models have been applied toward the solution of a variety of engineering problems, such as the closure of and loads on tunnels, chambers, and pillars in creep-sensitive materials, such as salt, shale, and fault zones. Highly stressed and creep sensitive ground encountered in underground excavations is described in tunnel man’s terminology as squeezing ground, inasmuch as it leads to a gradual closing of the opening under practically undrained conditions.

Undrained creep behavior is closely related to the *drained creep* phenomenon associated with secondary consolidation and swelling inasmuch as the mechanisms that cause volume change.

Several workers have studied creep of pillars in underground mines, particularly salt and potash mines. Those studies indicated that deformation of pillars did not occur instantaneously but increase with time. Pillars, which appear stable after mining may deteriorate with time and subsequently fail due to the development of limiting vertical deformation. Pillar failure takes place at a range of vertical stresses; failure at high stresses taking place earlier than at low stresses.

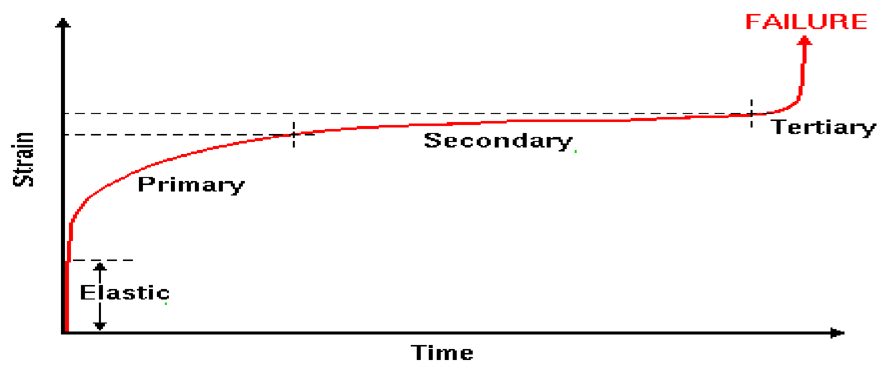


Figure2 standard creep behavior

The knowledge of deformational characteristics of the supporting pillars is essential for designing the mine workings, and also helps in determining the life of the pillars underground. The time taken by a pillar to reach an unstable condition can be calculated from an experimental value of the maximum possible vertical deformation and the rate of convergence measured in situ. The value of deformation at which the deformation at which the deformation rate starts to accelerate is chosen as the boundary between stability and instability.

Pomeroy carried out creep experiments on a number of coal specimens and found that anthracite did not creep and always failed explosively. He related this to the frequent occurrence of out bursts in anthracite mines. If coal creeps the stresses are easily accommodated as workings advance and the strength of coal is not exceeded; but if coal does not creep as is the case with anthracite, its strength is exceeded and this results in violent outbursts.

The results of creep studies are useful for predicting slope failure as well. Saito has described a method of predicting the time of slope failure by means of steady state creep rate. In a later paper he has also described another method of predicting time of a land slide by the tertiary creep method. It is quite likely that sometimes only tertiary stage creep is observed because of the late installation of devices at the site.

Maranini and Brignoli (1999) experimented uniaxial, triaxial, and hydrostatic tests (both standard tests and creep tests) to know the behavior of PietraLeccese. This rock is massive unfractured limestone. The predominant deformation mechanisms were crack propagation (at low confining pressures) and pore collapse (at higher stresses). During creep tests, the squeezing of pores lead to lowering of the yield stress, in triaxial and hydrostatic configurations.

Price (1964) carried out bending and compressive creep tests on different sandstones, a siltstone, and muddy limestone. He showed that a Bingham-Voigt model, mostly described results of the bending tests. Using the results of Price's bending tests on Pennant Sandstone, Boukharov *et al.*(1995) used time effect models for each stage of creep and applied the models to explain deflection of beam over time.

Price's (1964) tests included the most of the work done yet on coal-measure rock. Wawersik (1985) experimented intact and jointed rock specimens namely Westerly Granite and Navaho Sandstone in uniaxial and tri-axial compression. Creep of the rock was observed, mostly when water was present. And in clean, interlocked joint very little creep was seen. Based on this, Wawersik concluded that the creep behavior of jointed rock has the same character as that of the intact material, but with a larger amount of strain.

Considering Wawersik's observation and the large strains needed to account for the amount of roof sagseenin some coal mines, it is likely that creep in brittle coalmine occurs because of (1) micro-cracking along weak bedding planes and (2) weakening of asperities of joints. Because of the much friable character of the mudstone analyzed in this study along bedding, it can be seen reasonable to conceptualize the shear plane in the mudstone as a cohesive quasi-joint. For a joint, it is important to actuate frictional properties in addition to creep characteristics.

Amadei (1979) and Amadei and Curran (1980) experimented direct-shear and tri-axial tests on unfilled clean joints sawn in specimens of sandstone, limestone, marble, and granite.Theysaid that shear displacement was of the form

$$\Delta u_s(t) = A \log_{10}(t + 1) + B + Ct$$

where *A*, *B*, and *C* are constants which depend on the ratio of applied shear stress to peak shear strength, properties of the intact rock, and joint surface conditions, respectively.

Solberg et al.(1978) conducted tri-axial tests on Westerly Granite with saw-cut joints filled with crushed Westerly Granite. A confining pressure of 400 MPa (58,000 psi) was applied.

They found a correlation between differential stress and creep rate. Above a differential stress of 1,083 MPa (157,100 psi), primary and secondary and lastly tertiary creep were followed and violent fractured.

Höwing and Kutter (1985) conducted a study of the effects of joint filler on creep behavior. During the primary phase creep velocity follows a power law. Creep progressed from the primary to the tertiary phase.

Bowden and Tabor (1964) defined the coefficient of friction as the ratio between shear stress, σ_s , and normal stress, σ_n ,

$$\sigma_s = C_o + \mu\sigma_n$$

In agree with Amonton's definition. The Coulomb law in which $C_0$is inherent joint cohesion and μ is coefficient of friction is backed by Jaeger(1959) and by tests of Byerlee(1978). Other well-known definitions of frictional strength were provided in Barton (1974) and Ladanyi and Archambault. friction laws can be placed in one of three classes: displacement weakening, velocity-dependent (velocity weakening), or normal-stress-dependent (normal stress weakening).

The class displacement weakening appends laws such as Patton's (1966) bilinear model, Jaeger's (1959) variation of that model that appends a smooth transition between linear segments, and Cundall and Hart's (1984) continuously yielding joint model that was explainedlater by Cundall and Lemos (1990). In the latter paper, bounding shear strength was used. This bounding shear strength was incrementally lowered as shear displacement continued.

Many researchers have conjectured or used plasticity models with a non-associated flow rule to make joint friction and implement a softening law (e.g., Michalowski and Mróz, 1978; Plesha 1987; Fakhimi, 1992; Lofti and Shing, 1994; Mróz and Jarz_bowski, 1994; Jarz_bowski and Mróz, 1994; Mróz and Giambanco, 1996). Softening is usually dependent on the amount of frictional work done.

Lippmann (1990) canvassed the act of friction between a coal seam and overlying and underlying rock layers in the occurrence of translational coal bumps. Detonations, earthquakes, or other seismic events may accomplish waves along interfaces and thus may transform static friction to sliding friction.

Most of the researches in velocity-dependent friction laws are concerned with the study of friction along faults. Dieterich's direct-shear experiments on granodiorite (1979) demonstrated that competing time, displacement, and velocity effects handle overall friction of a specimen, and so he proposed a simple law. Others (Dieterich; Ruina; Rice; Rice and Ruin) have postulated various state-variable friction laws. Generally, these laws describe a velocity-dependent friction with transitions over time between friction levels.

Only limited studies and discussions about the effects of normal stress changes on friction have been published. Results of some experiments do not show any effects of normal stress history (Olsson, 1987; Lockner and Byerlee, 1986), while others do (Hobbs and Brady, 1985; Olsson, 1985, 1987, 1987, 1988; Linker and Dieterich, 1986).

Given the nature of mining problems, velocity and normal stress dependence are likely to be second-order effects. Displacement dependence will likely be more significant. Many research results demonstrated that salt rock exhibits pronounced time-dependent deformation or creep under relatively low stress level and has very low permeability and porosity. Salt rock can creep to a very large strain without fracturing and tends to be self-healing. In recent years salt rock is considered as in ideal material for the storage of natural gas, petroleum and wastes, especially nuclear wastes, e.g. Waste Isolation Pilot Plant of USA. It is very important to investigate the time-dependent properties of salt rock in many engineering applications. For this reason, many authors have investigated the time-dependent behavior using uniaxial and tri-axial tests and Pacheco conducted detailed tri-axial creep tests using hollow cylindrical specimens. Carter investigated the influence of temperature effects on creep behavior and found that the time-dependent properties of salt are very strongly dependent on the temperature. Various so-called `deformation mechanism maps' have been proposed in order to locate the domain in the stress–temperature–strain rate space, where each of the different processes controls the inelastic flow under steady-state conditions. A large number of uniaxial and tri-axial test results and analyzed the confining pressure effects on the creep strain. This longstanding interest in salt rock behavior has resulted in numerous studies, e.g. studies on relaxation and creep behavior under cycle loading.

Lomenick and Bradshaw (1969) reported on an extensive testing program that included the effects of load, temperature, temperature elevation after initial loading, shale partings, pillar shapes, salt samples from different localities reproducibility of results,ultimatestrength , mechanisms of deformation, and long-term creep. That study resulted in the well known power-law pillar creep formula:

$$\varepsilon = 1.30 \times 10^{-37}\ T^{9.5}\ \sigma^{3.0}\ t^{0.3}$$

where E is the pillar shortening of **a** model pillar initially 25 mm (1 in .) high, T is absolute temperature (K) , σ is the initial average pillar stress (psi) (1 MPa = 145 psi) , and t is time in hours. Equation holds for cylindrical model pillars with a width-to-height ratio of 4 fabricated from salt core from Lyons, Kansas Three types of tests are common in experimental studies of the rheological behavior of rocks;

1. Creep tests, with a constant homogenous stress state
2. Constant strain rate tests which examine brittle rock behavior and long term strength level
3. Relaxation tests or constant strain state tests, which are used to define the lower stress limit that can produce creep deformation.

2.4 Properties of rock: Rock properties play major role in the behavior of the rocks as well as excavation stability. Hence evaluations of those properties are important. Those are typically physical and mechanical.

2.4.1 Physical properties:-

2.4.1.1. Hardness:-

Hardness is the characteristic of a solid material expressing its resistance to permanent deformation. Hardness of a rock material depends on several factors, including mineral composition and density. A typical measure is the Schmidt rebound hardness number.

2.4.1.2. Abrasivity:-

Abrasivity measures the abrasiveness of a rock materials against other materials, e.g., steel. It is an important measure for estimate wear of rock drilling and boring equipment.

Abrasivity is highly influenced by the amount of quartz mineral in the rock material. The higher quartz content gives higher abrasivity.

2.4.1.3. Permeability:-

Permeability is a measure of the ability of a material to transmit fluids. Most rocks, including igneous, metamorphic and chemical sedimentary rocks, generally have very low permeability. As discussed earlier, permeability of rock material is governed by porosity. Porous rocks such as sandstones usually have high permeability while granites have low permeability. Permeability of rock materials, except for those porous one, has limited interests as in the rock mass, flow is concentrated in fractures in the rock mass.

2.4.1.4. Wave velocity:-

Measurements of wave are often done by using P wave and sometimes, S waves. P wave velocity measures the travel speed of longitudinal (primary) wave in the material, while S-wave velocity measures the travel speed of shear (secondary) wave in the material. The velocity measurements provide correlation to physical properties in terms of compaction degree of the material. A well compacted rock has generally high velocity as the grains are all in good contact and wave are travelling through the solid. For a poorly compact rock material, the grains are not in good contact, so the wave will partially travel through void (air or water) and the velocity will be reduced (P-wave velocities in air and in water are 340 and 1500 m/s respectively and are much lower than that in solid).

2.4.2. Mechanical properties of rock strength:-

2.4.2.1. Compressive strength:-

Compressive strength is the capacity of a material to withstand axially directed compressive forces. The most common measure of compressive strength is the uniaxial compressive strength or unconfined compressive strength. Usually compressive strength of rock is defined by the ultimate stress. It is one of the most important mechanical properties of rock material, used in design, analysis and modeling.

2.4.2.2. Young's Modulus and Poisson's Ratio:-

Young's Modulus is modulus of elasticity measuring of the stiffness of a rock material. Itis defined as the ratio, for small strains, of the rate of change of stress with strain. Thiscan be experimentally determined from the slope of a stress-strain curve obtained during compressional or tensile tests conducted on a rock sample.

Similar to strength, Young's Modulus of rock materials varies widely with rock type. For extremely hard and strong rocks, Young's Modulus can be as high as 100 GPa. There is some correlation between compressive strength and Young's Modulus.

Poisson's ratio measures the ratio of lateral strain to axial strain, at linearly-elastic region. For most rocks, the Poisson's ratio is between 0.15 and 0.4. As seen from early section, at later stage of loading beyond linearly elastic region, lateral strain increase fast than the axial strain and hence lead to a higher ratio.

2.4.2.3. Stress-Strain at and after Peak:-

Strain at failure is the strain measured at ultimate stress. Rocks generally fail at a small strain, typically around 0.2 to 0.4% under uniaxial compression. Brittle rocks, typically crystalline rocks, have low strain at failure, while soft rock, such as shale and mudstone, could have relatively high strain at failure. Strain at failure sometimes is used as a measure of brittleness of the rock. Strain at failure increases with increasing confining pressure under tri-axial compression conditions.

Rocks can have brittle or ductile behavior after peak. Most rocks, including all crystalline igneous, metamorphic and sedimentary rocks, behave brittle under uniaxial compression. A few soft rocks, mainly of sedimentary origin, behave ductile.

2.4.2.4.Tensile Strength:-

Tensile strength of rock material is normally defined by the ultimate strength in tension, i.e., maximum tensile stress the rock material can withstand. Rock material generally has a low tensile strength. The low tensile strength is due to the existence of micro-cracks in the rock. The existence of micro-cracks may also be the cause of rock failing suddenly in tension with a small strain.

Tensile strength of rock materials can be obtained from several types of tensile tests: direct tensile test, Brazilian test and flexure test. Direct test is not commonly performed due to the difficulty in sample preparation. The most common tensile strength determination is by the Brazilian tests.

2.4.2.5.Shear Strength:-

Shear strength is used to describe the strength of rock materials, to resist deformation due to shear stress. Rock resists shear stress by two internal mechanisms, cohesion and internal friction. Cohesion is a measure of internal bonding of the rock material. Internal friction is caused by contact between particles, and is defined by the internal friction angle,φ. Different rocks have different cohesions and different friction angles.

Shear strength of rock material can be determined by direct shear test and by tri-axial compression tests. In practice, the later methods is widely used and accepted.

CHAPTER 03

Experimentation

The goal of the investigation is to evaluate the creep behavior of the rock. A number of experiments were carried out to achieve it as mentioned below.

3.1 Creep Test

3.1.1. Method for determining creep or stress relaxation behavior:-

To determine creep properties, material is subjected to prolonged constant tension or compression loading at constant temperature. Deformation is recorded at specified time intervals and a creep vs. time diagram is plotted. Slope of curve at any point is creep rate. If failure occurs, it terminates test and time for rupture is recorded. If specimen does not fracture within test period, creep recovery may be measured. To determine stress relaxation of material, specimen is deformed a given amount and decrease in stress over prolonged period of exposure at constant temperature is recorded. Standard creep testing procedures are detailed in ASTM E-139, ASTM D-2990 and D-2991 (plastics) and ASTM D-2294 (adhesives).

3.1.2. Principle:-

A test piece of given dimension is heated under specified conditions to a given temperature and at one of two specified stages in the test a constant compressive load is applied to it. The deformation of the test piece at constant temperature is recorded and the percentage change is evaluated as a function of time.

There are two forms of test one where the load is applied at room temperature and the other where it is applied at the test temperature.

3.1.3. Apparatus:-

3.1.3.1. Loading device:-

The loading device is capable of applying a load centered on the common axis of the loading columns, the test piece and the supporting column and directed vertically along this axis at all the stages of the test. The loading device consists (Figure)of

- Fixed column
- Moving discs
- Arrangement of two discs, two columns, two discs,
- Furnace

Fig.3 The Load frame used to determine the creep behavior

3.1.3.1.1. Fixed column:-

The fixed column has a 45 mm in overall diameter with an axial bore.

3.1.3.1.2. Moving column:-

The moving column has diameter of 45 mm too that moves vertically.

3.1.3.1.3. Two discs:-

The loading discs are of 5mm to 10mmthick and 50mm in diameter of material compatible with the material under test which are placed between the test piece and the fixed column and have a central bore. The ends of the fixed and moving columns are plane and perpendicular to their axes, the faces of each disc are plane and parallel.

The columns and disc is capable of withstanding the applied load up to the final test temperature without significant deformation. There is no reaction between the discs and the loading system. The figure no 2 Shows the loading device used.

Fig.4 loading apparatus of test

3.1.3.1.4. Furnace:-

The heating plates are capable of raising the temperature of the test piece to the final test temperature at specified rate in an atmosphere of air. The temperature controller is attached to the sides of the loading frame and has a relay controller (Figure 3).

Fig.3 furnace of the test

3.1.3.1.5. Measuring device:-

The distance between the loading platens is measuring by a vernier caliper with least count 0.01 mm.

3.1.4. Procedure:- The procedure of tests are described below.

1. The height of the test piece was measured and the diameter as well.
2. A constant compressive load was applied.
3. Desired temperature was applied on the specimen.
4. The changes in strain of the specimen was measured at regular interval.
5. Strain was noted.
6. Temperature and stress was raised until the fracture of the specimen.

CHAPTER 04

Results and discussion

The investigation aimed at evaluating the creep behavior of the rocks at varying temperature and pressure. The tests carried out to do those are reported below. About 3 to 4 samples were tested for each parameter and their average are reported here.

4.1.Observation:

4.1.1. UCS observation;

L/D=4.752/4.752=1

Load in KN	Axial deformation In mm	Lateral deformation in mm
10	0.00	0.01
20	0.01	0.34
30	0.10	0.35
40	0.21	0.35
50	0.55	0.35
55	1.02	0.81

Table 1

2.1.1 Creep test of chromite ore:-

Load =10KN

Temperature=50^0C

Time In min.	Initial length In cm	Final length In cm	∆L
0-10	6.272	6.235	0.037
10-20	6.235	6.197	0.038
20-30	6.247	6.233	0.036
30-40	6.233	6.219	0.037
40-50	6.219	6.2055	0.038
50-60	6.2055	6.1917	0.038

Table 2

Load= 20KN

Temperature=60^0C

Time in min.	**Initial length in cm**	**Final length in cm**	**ΔL in cm**
0-10	6.258	6.255	0.003
10-20	6.255	6.249	0.006
20-30	6.249	6.2425	0.0065
30-40	6.2425	6.2345	0.008
40-50	6.2345	6.227	0.0075
50-60	6.227	6.2188	0.0082

Load= 20KN

Temperature=70^0C

Time in min.	**Initial length in cm**	**Final length in cm**	**ΔL in cm**
0-10	6.272	6.260	0.012
10-20	6.260	6.247	0.013
20-30	6.247	6.233	0.014
30-40	6.233	6.219	0.014
40-50	6.219	6.2055	0.0135
50-60	6.2055	6.1917	0.0138

Table 4

Load=30KN

Temperature=80^0C

Time in min.	**Initial length in cm**	**Final length in cm**	**∆L in cm**
0-10	6.200	6.191	0.009
10-20	6.191	6.179	0.012
20-30	6.179	6.1664	0.0126
30-40	6.1664	6.1534	0.013
40-50	6.1534	6.1406	0.0128
50-60	6.1406	6.1274	0.0132

Table 5

Load=40KN

Temperature=90^0C

Time in min.	**Initial length in cm**	**Final length in cm**	**∆L in cm**
0-10	6.126	6.121	0.005
10-20	6.121	6.114	0.007
20-30	6.114	6.1065	0.0075
30-40	6.1065	6.0989	0.0076
40-50	6.0989	6.0913	0.0076
50-60	6.0913	6.0833	0.008

Table 6

Load=50KN

Temperature=1000C

Time in min.	**Initial length in cm**	**Final length in cm**	**∆L in cm**
0-10	5.994	5.992	0.002
10-20	5.992	5.990	0.002
20-30	5.990	5.989	0.0018
30-40	5.989	5.987	0.002
40-50	5.987	fractured	

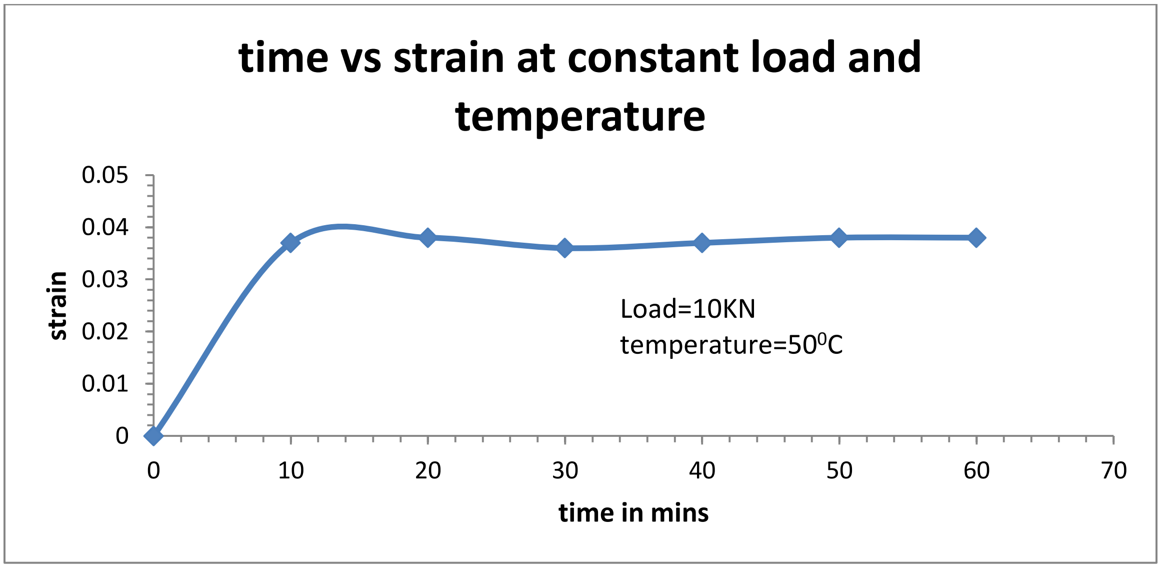
Table 7

Fig. 6 A typical photo of a fractured sample

Comparison of strain at 60^{0}C and at 70^{0}C at same load (20 KN)

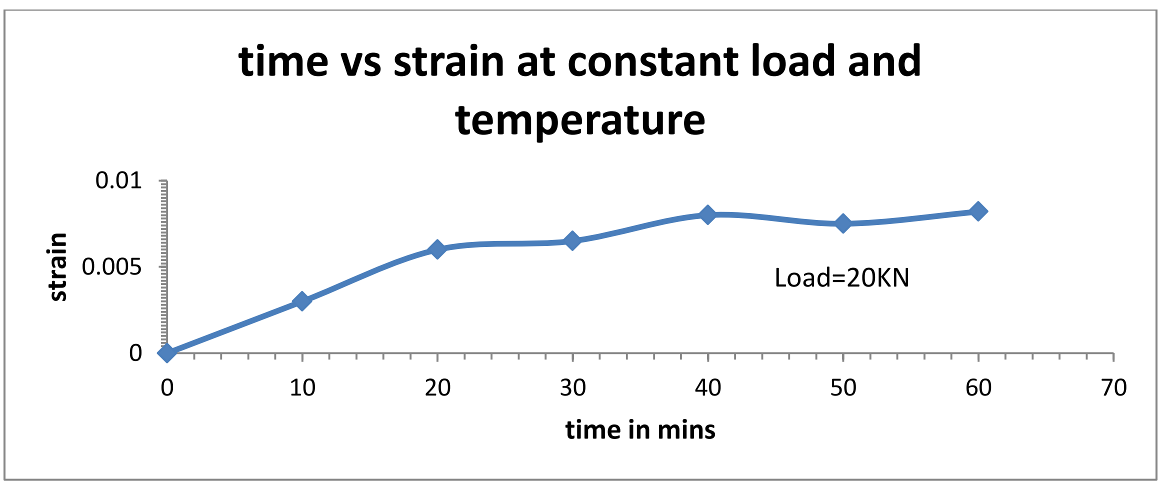
Time	Strain at 60^{0}C		Strain at 70^{0}C		%diff. at 60^{0}C	%diff. at 70^{0}C
0-10	6.258	6.255	6.272	6.260	0.048	0.191
10-20	6.258	6.248	6.272	6.254	0.159	0.286
20-30	6.258	6.248	6.272	6.240	0.159	0.510
30-40	6.258	6.240	6.272	6.226	0.287	0.733
40-50	6.258	6.237	6.272	6.220	0.335	0.829
50-60	6.258	6.232	6.272	6.212	0.415	0.956

Graphs of creep test of chromite ore: The results of the creep testing were plotted for analysis. Grpahs were drawn in Microsoft Excel (2007) program.



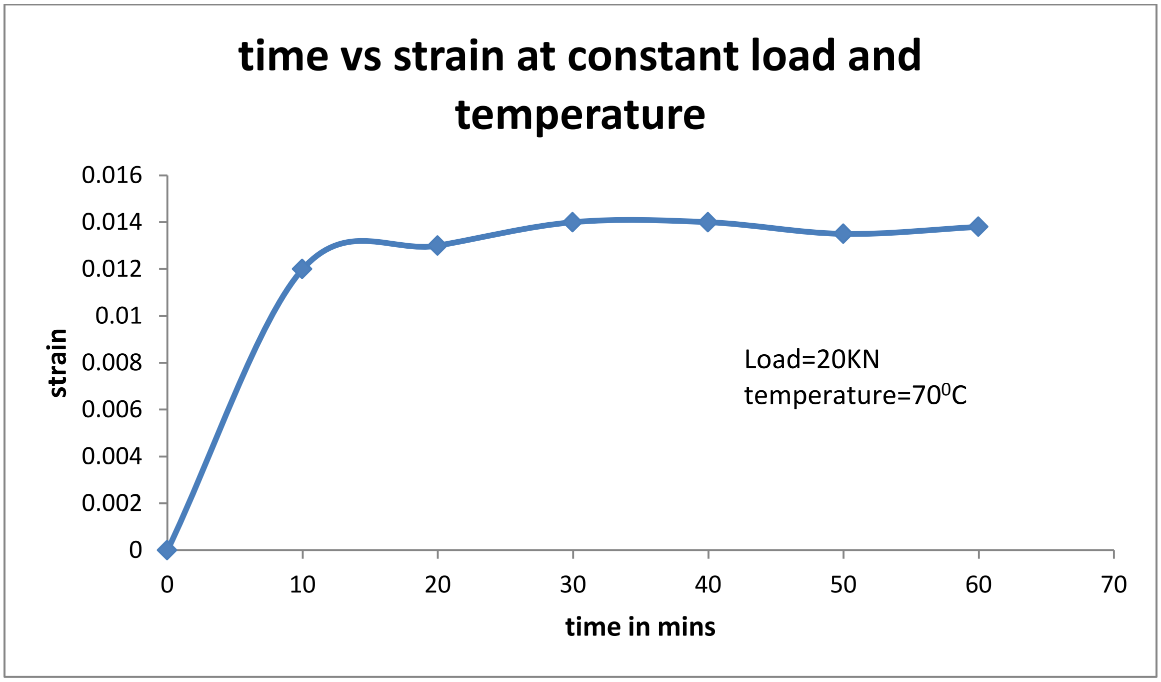
Graph 1

Rock sample were tested for compressive loading. Axial strain were measured up to failure. It is observed that at 10KN load and 50^0C, the rate of deformation is very sharp during first 10min of testing. Then the rate gain in strain is more or less stable. The strain could not be recovered beyond 60 minutes or sample crushed under loading.



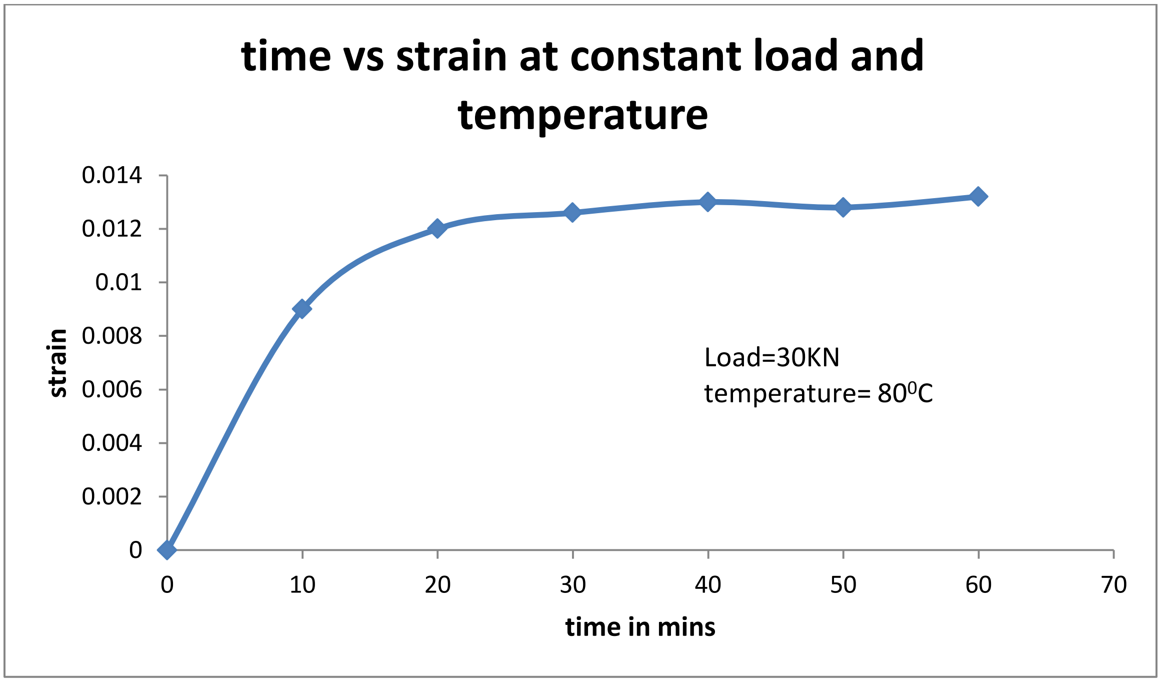
Graph 2

Rock sample were tested for compressive strength. It is observed that at load 20KN and temperature 60^0C the strain rises in a straight line upto 20mins then it decreases slightly and increases slightly and this phase is known as secondary creep stage and this phase is followed by tertiary creep phase.



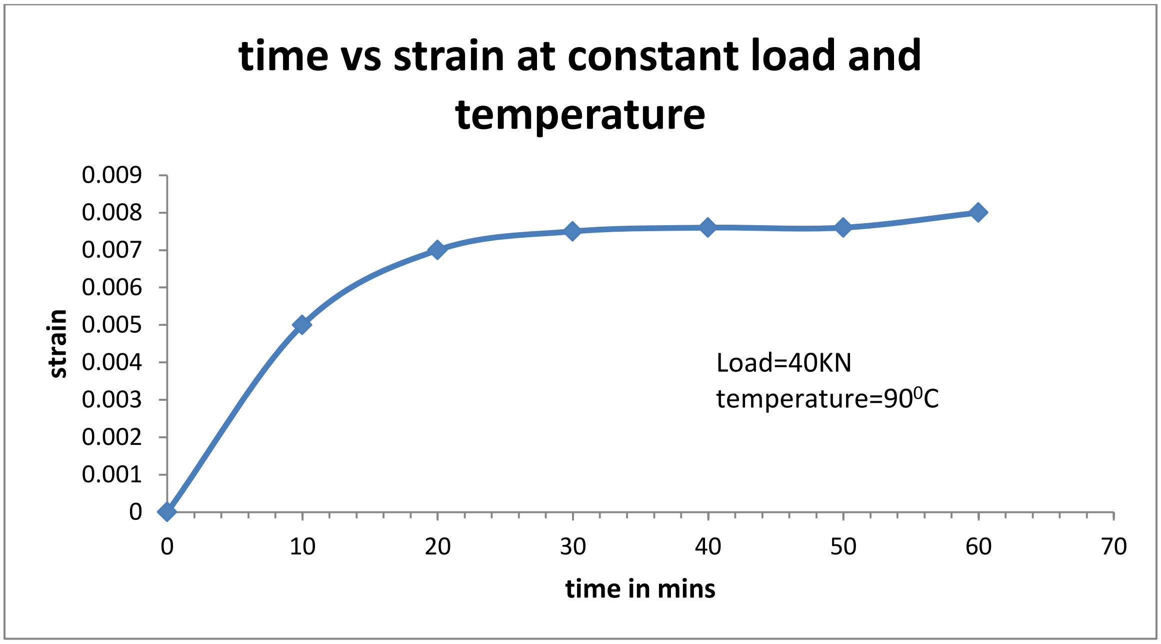
Graph 3

After testing the sample at Load 20KN and temperature 70^{0}C it was observed that the graph is linear upto 10mins and then remains constant indicating the primary and secondary creep phases.



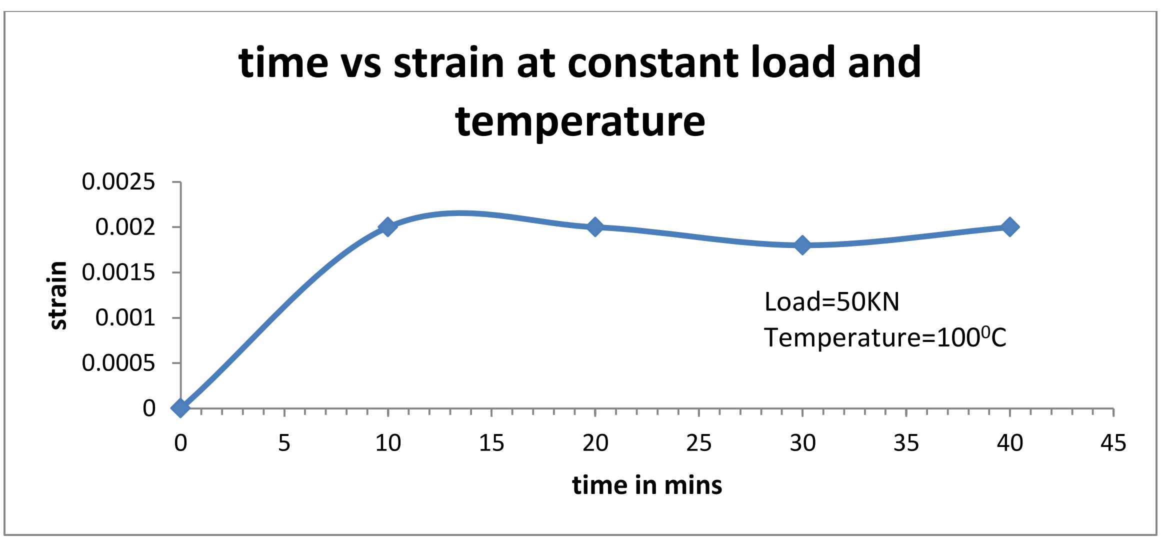
Graph 4

After testing at load=30KN and temperature 80^{0}C, it was observed that the curve is just like the logarithmic curve where the curve is linear upto 10mins and the it follows a curve path followed by constant path. Here also primary and secondary phase is seen.



Graph 5

Load at 40KN and temperature at 90^{0}C is similar to the previous one where the curve is linear to first 10 mins and then follows a curve path. Here also primary and secondary creep is observed with a slight tertiary creep phase.



Graph 6

When the test specimen was applied a load 50KN and temperature 1000C the primary creep is seen up to 10mins where the curve is linear and then it decreases to 30 mins followed by a increase up to 40 mins showing secondary and tertiary creep phase respectively.

5. Results:-

The failure load of the sample is decreased as temperature increased. The failure load at room temperature found to be 55KN but when the temperature increased to 100^0C the failure load is decreased and found to be 50 KN.

6. Conclusion:-

1. All the three stages of an idealized creep curve were observed in the Sicilian marble specimens. The steady state creep rate was found to increase with the increased stress.
2. The mode of fracture of specimen in the creep rig was similar to the mode observed during the uniaxial compression tests.
3. Strain rate is steep for initial 20mins then the rate of strain becomes very moderate
4. Strain between 20-40mins is more or less constant confirming to secondary creep behavior at 30KN and 80^0C
5. Maximum strain is found at 10 KN and 50^0C in the time 40-60 mins. The maximum strain is found to be 0.038.

Recommendation:-

This investigation was undertaken as a part of final year project with a fixed time limit. Hence many aspects of creep behavior could not be investigated. In future research may be carried out by considering more rock samples from different site for better understanding of the subject in detail.

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