Temperature Effects on Physico-Mechanical & Mineralogical properties of Sandstone Rock

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Summary

Increase in temperature of strata causes change in physical & mechanical properties of rocks thereby causing instability in the strata which results in rock failure & surface subsidence. Knowing these effects for a region helps in planning and reducing its impact on the operations.

In this study, sandstone rock samples are collected from Damodar River Valley of Dhanbad, India and have been tested subjected to laboratory experiments.

Individual rock samples were heated to a different temperature starting from 200degC to 1200degC. They were heated at specified temperatures for 6 hours continuously and then left in the furnace, then heated again for 6 hours the next day till 7 days. Post heating of rock samples for 42hours to a defined temperature, their physical properties (minerology, grain size and water holding capacity) and rock mechanical properties (Uniaxial compressive strength, tensile strength, ultrasonic wave velocities etc.) were determined.

Results shows that temperature has significant effect on the rock strength. Trend observed on UCS versus temperature crossplot suggest an increase in strength upto 500DegC and then decrease upto 1200DegC. This behavior is attributed to change in compactness with temperature observed on thin section analysis. Rock samples post heat treatment, shows change in porosity due to chemical & structural change in quartz & feldspar grains. The rock gets more porous with increase in void spaces. It is observed that compactness decreases upto 800DegC and then a gradual increases upto 1200DegC. The decrease in size and amount of quartz grains with increase in temperature followed by large increase in uneven fractures in quartz grains affected the rock strength. Because of the changes at granular level, most of the physical and mechanical properties of the sandstone rock are influenced.

These results of the laboratory experiments and methods adopted are discussed in detail in the paper.

Introduction

Temperature alters the physical & mechanical properties of rocks and thereby might cause instability leading to different challenges originated linked with rock failure & surface subsidence. Assessing the temperature effects on rock properties will enable us in pre-estimate its effects (Brodsky et al., 1985; Török et al., 2005).

This study is another step in this direction, where sandstone samples heated to different temperature levels upto 1200degC and are tested for physical and mechanical rock properties in the laboratory.

Workflow:

Sandstone rock samples are collected from Damodar River Valley near Dhanbad district or Jharkhand. These rock samples were taken to rock mechanics laboratory for further testing. Individual rock samples were heated to a different temperature starting from 200degC to 1200degC. They were heated at specified temperatures upto 1200 DegC for 6 hours continuously and then left in the furnace, then heated again for 6 hours the next day till 7 days.

These rock samples heated to different temperatures were tested in laboratory to investigate the effect of high temperature on physico-mechanical properties of sandstone through laboratory experiments. *ISRM*[3] *or* ASTM suggested methods are used for performing these experiments. Following physical and mechanical properties were examined:

Physical properties:

- Mineralogy & grain size.
- Water holding capacity.

Mechanical properties:

- Rebound hardness.
- Shore Scleroscope hardness.

- Uniaxial compressive strength (Direct method) for Tangent & Secant modulus.
- Brazilian indirect tensile strength.
- Compressive strength (Indirect Method) using Protodyakonov's strength, Cone indenter index
- Ultrasonic wave velocities using Sonic logger

Temperature Effects on Physico-Mechanical & Mineralogical properties:

1. **Protodyakonov's Strength Test**: It is a indirect test for determining the rock strength. The test consists of crushing of rock sample of 25 - 75 gms into fragments larger than 10 mm contained in a hollow cylinder, by five successive drop- hammer/plunger blows. The percentage of rock that is broken down to pass a 0.5 mm sieve is used to calculate the Protodyakonov's index which gives an indication of strength of rock within practical limits. The height of -0.5 mm crushed rock is measured in a volumeter.

The compressive strength is related to the Index as **C_o (Mpa) = 100*f**, where f is the Protodyakonov's index.

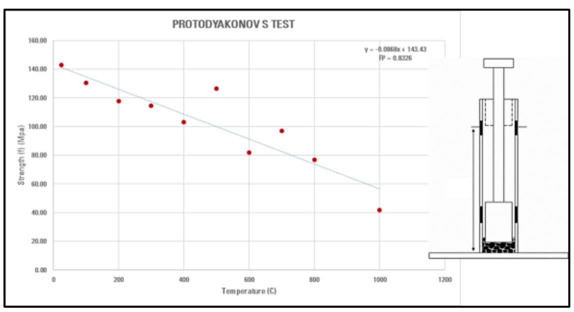

Figure 1: Variation of Protodyakonov's Strength with Temperature

2. NCB Cone Indenter Test: It was developed by the British National Coal Board to evaluate the compressive strength of rock by measuring the force required to cause a specific indentation in a small chip of rock under study. The test apparatus is designed to determine the hardness of rock by measuring its resistance to indentation by a hardened tungsten carbide cone.

The compressive strength is related to the Index as ***C_o(MPa) = 24.8 I_s***, where I_s is the Cone Indenter index in Standard Test .

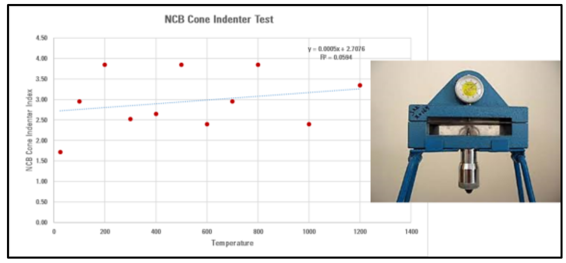

Figure 2: Variation of NCB Cone Indenter Index with Temperature

3. Ultrasonic Wave Velocity: Ultrasonic test is used as a method to determine the velocity of propagation of P and S waves in laboratory rock samples. In this technique, the frequency of wave should be high and rock specimens should have infinite extent compared to the wavelength of the pulses. The specimens can be rectangular blocks, cylindrical cores or even spheres (for determination of elastic symmetry of anisotropic rocks). This test is performed in accordance with the *ISRM suggested methods*[3]. The P wave velocity through a rock sample signifies the compactness of the rock sample

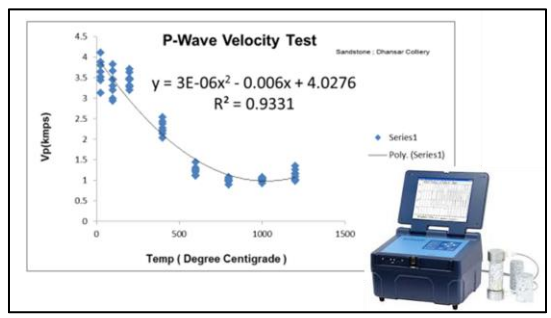

Figure 3: Variation of P-wave velocity with Temperature for all the samples

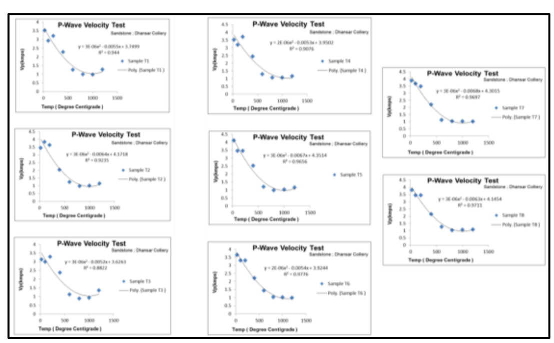

Figure 4: Variation of P-wave velocity with Temperature for different samples

Temperature Effects on Physico-Mechanical & Mineralogical properties of Sandstone Rock

4. Water Holding Capacity: Three samples were tested for water holding capacity. In this test, samples after getting heated in furnace at various temperatures, were immersed in a container containing water. The samples were left in the container for 2 days. The weight of the samples was taken before and after immersing them in water, the difference of which tells about their water holding capacity. This test is an indirect measure of porosity of rock sample, thus change in pore spaces can be related to the amount of water hold by the samples

5. Shore Hardness: The Shore Scleroscope hardness test measures the height of rebound of a diamond-tipped weight dropped from a given height on to a rock sample surface *(polished surface).* This test gives a hardness number which is a function of the coefficient of restitution for determination of hardness for the rock minerals (Altındağ, 2002).

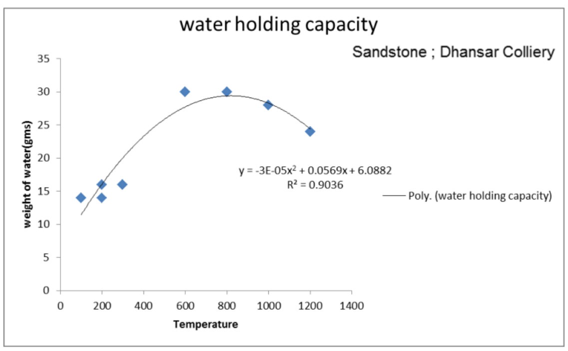

Figure 5: Variation of water holding capacity with Temperature

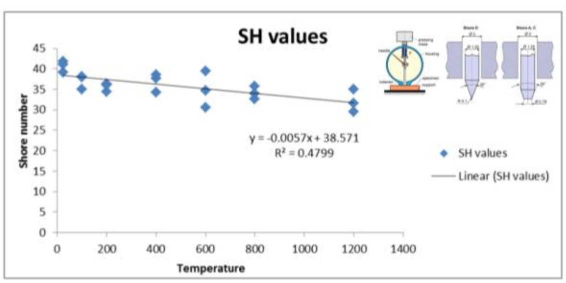

Figure 6: Variation of Shore Scleroscope hardness with Temperature

6. Schmidt Hammer Test: The Schmidt hammer test determines the rebound hardness of a test material. The plunger of the hammer is placed against the specimen and is depressed against the specimen. Energy is stored in the spring which automatically releases at a prescribed energy level and impacts the mass against the plunger. The height of rebound of the mass is measured on the scale and is taken as the measure of hardness.

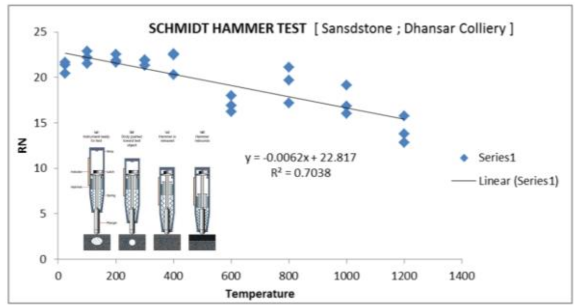

Figure 7: Variation of rebound hardness (RN) with Temperature

7. Uniaxial Compressive Strength Test: The compressive strength of a material is a measure of its ability to resist uniaxial compressive loads without yielding or fracture.

In the case of rocks, generally 2 types of brittle failure take place without much plastic flow and fracture is observed.

Specimens from drill cores are prepared by cutting them to the specified length and are thereafter grinded and measured. There are high requirements on the flatness of the end surfaces in order to obtain an even load distribution. Recommended ratio of height/diameter of the specimens is between 2 and 3. The specimens are loaded axially up to failure or any other prescribed level whereby the specimen is deformed, and the axial deformation can be measured using LVDT sensors.

The load-displacement curves are plotted using a data acquisition system [connected to LVDT & Load Cells], from the curves the breaking strength, tangent & secant modulus of rock sample can be calculated.

20 samples were tested for UCS Test, 3 samples for each temperature upto 1000 DegC & 2 samples for 1200 DegC test i.e. 3 samples were heated in furnace for 7 days [40-hour alternate heating] and then tested in laboratory for UCS test.

8. Brazilian Indirect Tensile Strength Test: The tensile strength of a material is a measure of its ability to resist uniaxial tensile loads without yielding or fracture. A direct-pull uniaxial test is difficult to apply to rock and in many cases some type of indirect test is employed to determine tensile strength. The Brazilian

Temperature Effects on Physico-Mechanical & Mineralogical properties of Sandstone Rock

test, where a disc of the test material is loaded across a diameter, is often employed. The technique involves loading disc-shaped specimens in compression across their diameter. Such loading generates a tensile stress at the center of the disc in a direction perpendicular to the direction of applied load (in the plane of the disc face). When the applied load reaches a critical level, the disc splits lengthwise in tension.

21 samples were tested for Brazilian Tensile Strength Test, 3 samples for each temperature i.e. 3 samples were heated in furnace for 7 days (40-hour alternate heating) and then tested in laboratory for tensile strength.

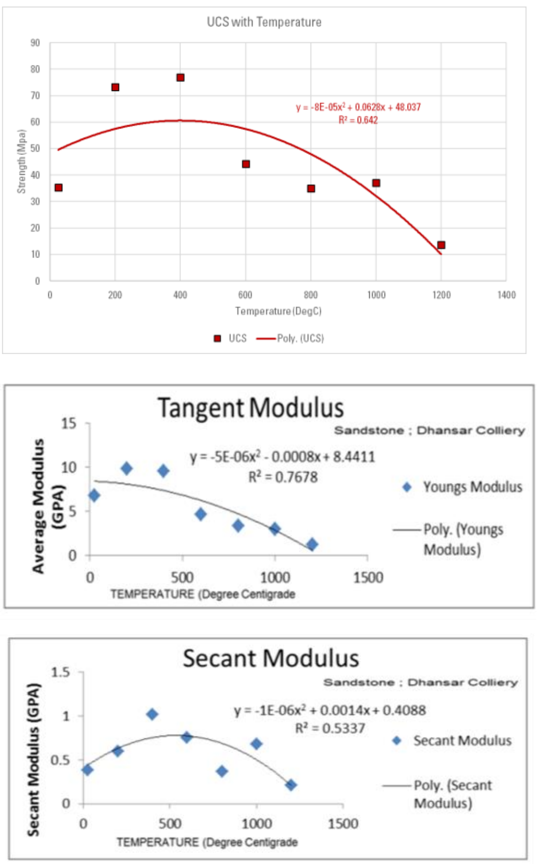

Figure 8: Variation of UCS, tangent modulus and secant modulus with Temperature

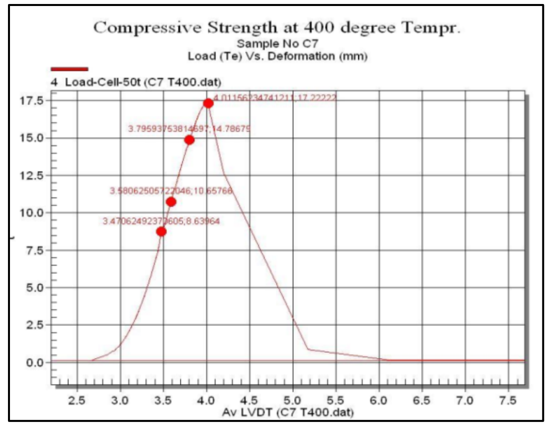

Figure 9: Stress strain profile obtained for a rock sample. UCS, tangent modulus and secant modulus are estimated from this curve.

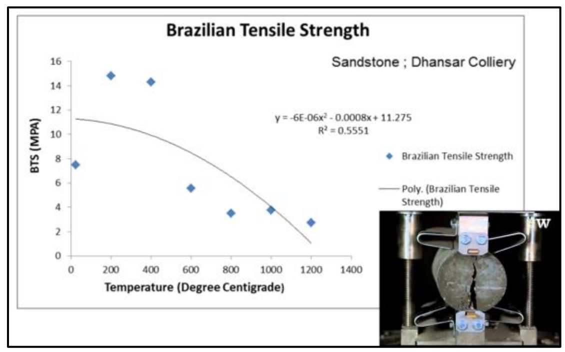

Figure 10: Variation of Brazilian tensile strength at various temperatures

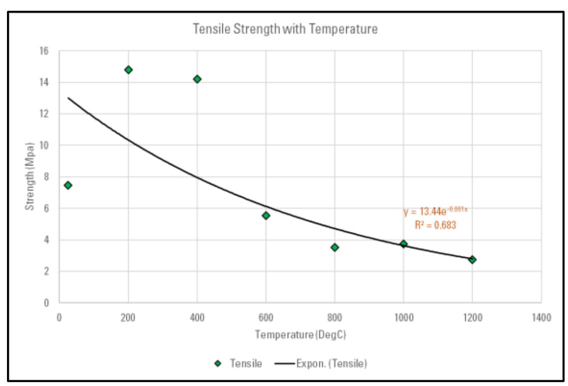

Figure 11: Load (te) versus time plot for determination of tensile strength by Brazilian test at 400deg centigrade for a rock sample

8. Mineralogy & Grain Size Study

Thin sections were prepared for sandstone rock samples heated to different temperatures to understand and analysis the changes at granular level. **Figure-12**

to 14 shows the microscopic view of thin sections prepared from rock samples. The summary of observations is listed in **Table-1**

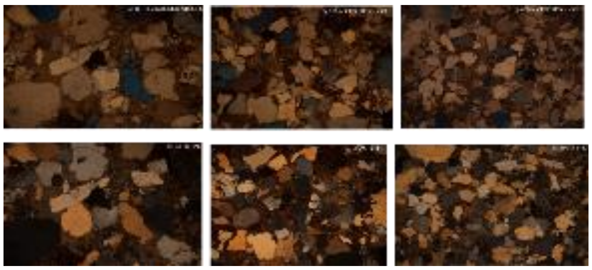

Figure 12: Observations on Thin Section Analysis at different temperatures at atmospheric, 200deg C and 400degC

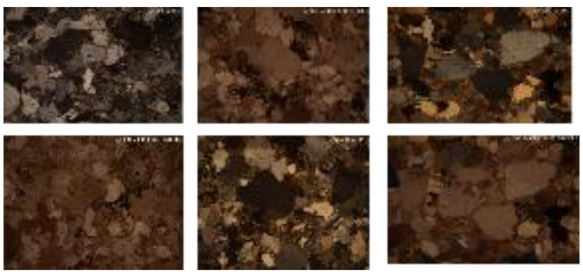

Figure 13: Observations on Thin Section Analysis at different temperatures at 600degC, 800degC and 1000degC

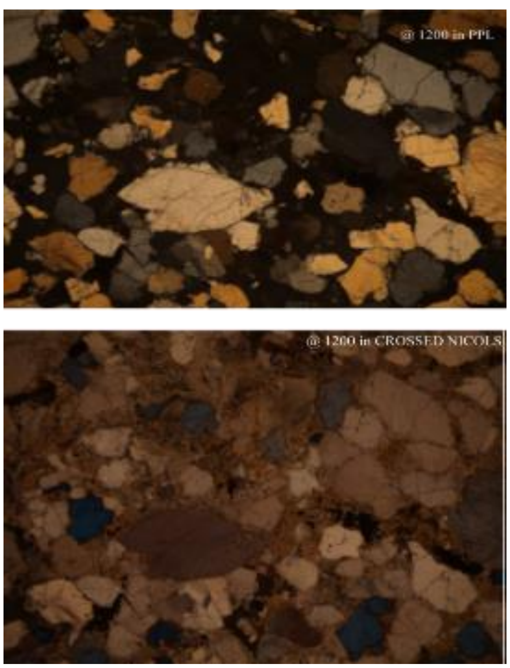

Figure 14: Observations on Thin Section Analysis at 1200degC temperatures

Table 1: Summary of observations observed on thin section analysis

Temp (DegC)	Observation
Room Temp (RT)	Mainly consist of Quartz grains, little feldspar(k), muscovite & other mica minerals. cementing material is fine silica.
200	Same as seen at room temperature.
400	Decrease in size of quartz grains, decrease in visibility of muscovite, quartz grains showed uneven fractures in them.
600	Same as in 400 with increase in visibility of feldspar, increase in fractures in quartz grains with little inclusion by surrounding cement.
800	Quartz grains decreases in number with more uneven fractures. A little appearance of garnet type mineral.
1000	Quartz grain in good number than previous, more mica minerals visible as binding material, highly fractured (uneven) quartz grains, quartz is of brittle nature.
1200	Quartz grains have no close contact with each other i.e. dispersed surrounded by cement, binding material increased, mica is less, quartz showed cherty appearance, high number of uneven fractures, some places brittle nature. 120-degree dihedral angle of quartz visible.

Conclusions

Based on the comprehensive experiments conducted sandstone rock samples at different temperatures following key take away points are summarized below:

- Protodyakonov's strength test showed a continuous decrease in strength on exposure to high temperatures.
- NCB Cone Indenter test showed almost no correlation amongst values with respect to change in temperature.
- Shore Scleroscope hardness showed a gradual decrease in hardness on exposure to high temperatures.
- Schmidt Hammer rebound test showed gradual decrease in strength.
- Sonic Logger showed continuous decrease in P-Wave velocity till 800 DegC and then a slight increase at upto 1200 DegC
- Water holding capacity increased continuously upto 800 DegC and a gradual decrease upto 1200 DegC
- Destructive tests showed that uniaxial compressive strength increase continuously upto 500 DegC & then

decreased continuously at high temperatures, at 1200 DegC the strength decreased to 38% of that at room temperature.

- Tensile strength also showed similar trend as compressive strength, firstly increased upto 400 DegC & then decreased upto 1200 DegC, at 1200 DegC the tensile strength decreased to 36% of that at room temperature.
- Mineralogical studies from thin sections showed decrease in size and amount of quartz grains with increase in temperature
- There was large increase in uneven fractures in quartz grains with increase in temperature, muscovite was clearly visible in mid-range temperatures like 400DegC & gradually disappeared at high temperatures.
- It is confirmed that temperature has great impact on rock strength, increase in strength upto 500DegC and then decrease upto 1200DegC can be attributed to change in compactness, porosity of rock and due to chemical & structural change in quartz & feldspar grains. The rock gets porous with increase in void spaces i.e. compactness decreases upto 800DegC and then a gradual increase upto 1200DegC
- The decrease in size and amount of quartz grains with increase in temperature followed by large increase in uneven fractures in quartz grains affected the rock strength.

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