

REVIEW ARTICLE

## Rock Mechanical Properties of Granite/ Clay/ Basalts/ Argillite / Glass and its Alterations at Different Temperatures-A Review

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### ABSTRACT

This paper presents a review of the effect of temperature in altering the rigid mechanical properties of materials like granite, clay, basalt, argillite and glass. Mechanical properties such as elasticity, stress, porosity, tensile strength and permeability of the materials were analysed at various temperatures. The analysis highlights the results and conclusions derived from numerous experimental works like tri-axial compression test, uniaxial test, etc. Apart from this, the impact of temperature on physical characteristics like colour, porosity, wave propagation and density were also studied. The main feature of this study is to showcase the acceptable range of temperature of the materials so as to avoid cracking and breaking of the materials during engineering applications. Moreover some back up techniques have been suggested to enhance the quality and strength of the materials.

**Keywords:** Temperature effect, Mechanical properties, Compression test, Uniaxial test, Physical characteristics.

### 1. INTRODUCTION

Mechanical property plays a significant role in highlighting the application and life span of a particular material. Different materials undergo transformation under the influence of temperature, loading etc. that alters their mechanical properties. In order to utilize these materials in engineering sector such as in construction sites and mine projects the analysis of mechanical properties is an essential one. Also, a clear perspective in the effect of temperature of materials aids in choosing good quality materials for design and construction applications.

In general, material strength depends upon mineral composition, grain magnitude, density, porosity, shape, temperature, loading effect etc. Of all these parameters, the most crucial one is the temperature. Steep increase in temperature causes permanent changes in the characteristics of rocks and materials which include cracking, destruction of the materials, declination in strength, etc. Generally materials like granite, clay, basalt, argillite and glass are

composed of numerous minerals. When these materials are heated, they get transformed into ductile material. Several tests such as uniaxial compression test, tri-axial test, shear test, indirect tension test, torsional test, punching test, etc. are available to determine the strength of the material.

Some of the general facts are as follows:

- Larger the particle size, higher will be the breaking strength.
- When temperature goes high, the breaking strength reduces.
- As porosity increases, strength of the material reduces.
- As temperature increases, textural and structural properties vary.
- Tensile and yield strength declines as temperature goes high.
- For same temperature, the tensile strength of the materials decreases greater than the compressive strength.
- Atmospheric pressure causes the deterioration of the materials.

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In recent years, several researchers have examined the mechanical properties of materials at elevated temperatures and its effects. Specimen of the materials were collected and subjected to different tests at high temperatures to estimate the changes in elasticity, young's modulus, permeability, tensile strength and compressive strength. When the specimens are subjected to elevated temperatures, thermal stress occur leading to the formation of micro cracks. [1] construed the thermo-physical characteristics of granite, basalt and sandstone at 25 – 100 °C to highlight that the presence of quartz plays a vital role on the thermal behaviour of the mentioned materials. By this investigation, it was concluded that when granite and sandstone are heated up to 573°C, morphological changes occur and heating above 870°C leads to the production of tridymite.

Subsequently after the experimentation, these materials can be used for several engineering and commercial applications such as,

- Granite rocks/ stones are generally utilized in interior and exterior constructional purposes.
- Clay finds application in pottery industry, constructional projects, etc.
- Basalt is used as fundamental material in the construction of roads and pavements.
- Argillite is normally used in exterior decorations.
- In packaging industry and decorative, tableware components, glass is used.

This paper highlights the results from studies which concentrated more on the impact of temperature on mechanical properties of granite, clay, basalt, argillite and glass.

## 2. METHODS OF TESTING MECHANICAL PROPERTIES BEHAVIOUR OF GRANITE IN HIGH TEMPERATURE

[2] proposed a novel technique that combines photography at 200 fps with digital image correlation in order to get the dislocation and stressed areas of granite samples. Although this method provides good results, the analysis could not be continued after the start of cracks in granite rocks. [3] highlighted the experimental analysis of the influence of heat on physical and mechanical characteristics of granite. Granite samples were investigated at a movement of 0.002 mm/s

with double strain gauges to obtain the axial and circumferential strains. Former gauge is kept parallel while the latter is kept in circumferential path. Equation (2.1) is used to calculate the volumetric strain of the granite.

$$\epsilon_v = \epsilon_a + 2\epsilon_r \quad (2.1)$$

whereas  $\epsilon_a$  and  $\epsilon_r$  are the axial and circumferential strains. The samples were tested at different elevated temperatures and hence the change in the stress level and elastic modulus were showcased in table 1. It can be concluded that the stress level shows small declination in the temperature range of 105 °C to 300 °C and displays quite high alteration at 500 °C and sharp change at 600 °C. Similar things happen for elastic modulus but with a different percentage scale.

Adapted from [3]

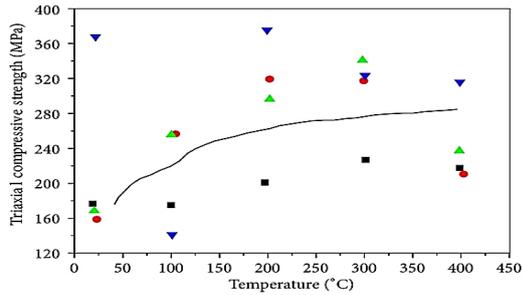
Table 1. Alterations in mechanical properties

Temperature °C	Stress at failure (Mpa)	Young's modulus (GPa)
105	244(±2.40)	75(±2.25)
300	224(±2.30)	62(±1.86)
500	194(±9.75)	54(±2.70)
600	128(±6.40)	28(±1.68)

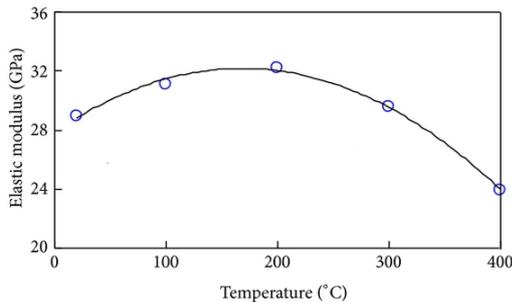
Different stages were distinguished from the stress-strain performance of the granite [4, 5] which includes crack closure, linear elastic deformation, crack initiation and stable crack growth. [6] revealed that crack closure raise in the range of 105 °C to 500 °C and reaches its peak at 600 °C leading to the development of micro-cracks. The creep strength of the granite decreases with increase in temperature thus determining the breakdown process.

[7] revealed the thermo-physical and mechanical characteristics and the consistency of granite at high elevated temperatures showcasing the uniaxial and tri-axial experiments. The threshold temperature of the granite is estimated to be 200°C. The test sample (granite) is subjected to breakdown without plastic reformation and this happens via two phases namely compact and linear elastic phases. The material is subjected to shear and tensile fractures at 400°C. The elastic modulus declines with raise in temperature. From 0 to 100°C and to 200°C there is no impairment to the granite. When the

temperature of the material increases, automatically the interior structure also changes. The effect of temperature in compressive strength and elastic modulus is displayed in figure 1 and figure 2. The black, red, green and blue colour denotes various pressure ranges such as 5, 10, 15, 20 MPa. From the two graphs, it can be concluded that the temperature magnitude needed to develop mechanical changes is 200°C.



Adapted from [7]  
Figure 1. Compressive strength vs. temperature



Adapted from [7]  
Figure 2. Performance of elastic modulus

Uniaxial and tri-axial creep tests were conducted at higher temperatures to examine the mechanical strength of granite. The results obtained for uniaxial compression tests highlights that with the increase of temperature, the curve become steeper. The elastic property of granite undergoes changes to viscoelasticity with temperature increase. [8] interpreted the interior morphology of granite at various temperatures and indicated that the uniaxial resistance of granite during compression shows greater declination for 25°C to 100°C than 100°C to 300°C. Also the crest strain exhibits sharp increase before 100°C and exhibits gradual increase after 100°C.

[9] inspected the nature of granite at different temperatures and highlighted that strength, crack failure and elastic modulus raised until 300°C and then declined. And also

in between 700°C-800°C, granite became ductile after peak stability. [10] highlighted the brittle-plastic transformation of the granite around 600°C and 800°C. [11] investigated the behaviour of granite from room temperature to 1200°C, specifying that the mechanical strength of the material exhibited no difference till 800°C and bearing aspect of the granite has been destroyed completely at 1200°C. The paper suggested that the main reason to the deformation of granite is thermal stress of the material.

[12] disclosed the loss of aesthetic characteristics of granite subjected to various temperatures using X-ray photoelectron spectroscopy. [13] Tri-axial analysis has been done on granite to determine the permeability of the material. During the initiation of micro cracks, the permeability decreases and then remains almost constant at the elastic region and gradually increases in the crack development area. [14] At the time of cooling, based on the grain size, the material stress occurs at the initiation of cracks. [15] manifested the modulation in porosity, gas permeability and some other physical properties of granite until the temperature becomes 600°C in surrounding pressure.

[16] When granite is heated, the elastic modulus and peak stress of the granite decrease whilst increasing the strain. Meanwhile for the temperature under 400°C the changes in the mechanical properties is very small and above 400°C the fatigue life of the granite decreases. [17] The destructive test has been conducted on granite at 800°C. The central stress of the granite declined at initial stage whereas the strain increased. And during 200°C-400°C, micro-cracks were formed. Also, decomposition of granite samples was noted above 400°C in uniaxial compression.

[18] Experiments were conducted on two different types of granite rocks. The young's modulus remains dynamic until 300°C and above this temperature the young's modulus gradually decreases. Indirect tensile strength revealed that during the initial stage, the strength of first granite increased and when subjected to higher temperature the strength of both the granites dropped. [19] Heat stress on the granite causes alterations in texture and structure thereby decaying the material. Granite displays brittle and quasi brittle behaviours in the certain temperature range of 100-200°C.

### **3. CHANGES IN THE MECHANICAL PROPERTIES OF CLAY**

[20] discussed the impact of some variations on the clay content that affect the mechanical and physical properties. When clay is heated up to 850°C, the young's modulus got decreased due to transposition of  $\beta$  and above 850°C there is no change. And also because of heating clay to 850°C, the thermal conductivity of the clay declined by 38% [21].

[22] justified the alterations in mechanical properties of clay when subjected to diverse stress conditions. When compression is applied, the yield threshold declined at high temperatures. [23] spelled out the conductive and mechanical properties of firebricks obtained from clay and petroleum dust. Even at higher temperatures, the crushing strength of the brick is found to be greater because of the addition of fine dust particles, in spite of reducing the density and conductivity.

[24] demonstrated the use of clay along with timber to safeguard construction structure which yielded good results by reducing the time and speed of charring. Further development has to be carried out in standardizing clay for better results. [25] elucidated the response of bentonite for a temperature range of 20°C to 120°C on its hydro-mechanical properties. With the increase in temperature the swelling capacity and pressure had decreased. Still it has been recommended to use bentonite up to a maximum temperature of 80°C because of its superficial characteristics such as small permeability, automatic healing capability and water holding ability.

[26] highlighted the improvement on the mechanical properties of clay bricks by the addition of waste glass substances. The bricks thus manufactured along with waste glass can be fired at 900°C rather than 1000°C. [27] A detailed summary on the impact of elevated temperatures on adsorbent clay that contribute to thermal, hydraulic, mechanical and chemical changes in it was provided. Two peak temperatures 100°C and 200°C were chosen and the survey concludes that clay at 200°C experienced more thermal stress than clay at 100°C.

[28] examined the usual and quite large sized rock samples of clay at 90-120°C and determined that the barrier characteristics of clay exhibited no change throughout the expelled temperature. The clay bricks were

burnt to 1050°C at diverse heating rates [29]. It is recommended to increase the heating rate to obtain bricks with low gas discharge though there is a downturn in physical and mechanical characteristics.

### **4. CONSEQUENCES OF HIGH TEMPERATURE ON THE MECHANICAL PROPERTIES BASALT**

[30] analysed the mechanical performance of basalt fibre roving and basalt polymer and it had been shown that basalt fibres offer high resistance to elevated temperatures. On the other hand, the flexible strength and the elastic modulus had declined up to 37.5% and 31% for basalt fibre roving and negligible depreciation occurred for basalt polymer in the range of 8.3% and 9.7%. [31] highlighted the advantages of basalt fibres with respect to available materials. Since basalt fibres had good mechanical properties, they have been used in between two materials to offer high strength.

[32] revealed the experimental study of composite coated with basalt fibres to determine the thermo-mechanical properties and phase transitions. Heating the material above 400°C reduced the tensile strength. [33] analysed the tensile characteristics of basalt fibre composite when subjected to different strain conditions and temperature. It has been disclosed that for a temperature up to 50°C, temperature has no impact on the tensile strength of the material and at 100°C the tensile strength reduces. [34] analysed the effect of temperature on basalt fibre reinforced plastic and steel joints at various load and temperature. It was observed that from -25°C-50°C the chain strength of the material increased and from 50°C-100°C chain strength decreased due to glass transition temperature.

[35] projected the characteristics and applications of basalt and glass fibres in immense strength concrete. [36] discussed the manufacturing process of strengthened basalt fibre polymer and also its features during the exposure to high temperature and alkaline solution. At 300°C the tensile and shear strength of the material got declined by 74.1% and at 135°C the decline percentage was 62.3. [37] evaluated the samples with low velocity (1.5 m/s) and 2.17J energy at three different temperatures 30°C, 50°C and 65°C. The analysis endorsed that flexural and impact

potential of basalt composite minimized at higher temperatures.

[38] Tri-axial test was performed to evaluate the samples in which pressure was increased in steps up to 190 MPa. It was deduced that mechanically persuaded cracks has less impact than existing cracks. [39] The tensile strength of basalt/ polypropylene clay nano-composites was very high at -165°C. The young's modulus and the yield strength of both the materials were good at -196°C, decreases up to 25°C and very poor at 120°C.

### **5. MECHANICAL CHARACTERISTICS OF ARGILLITE AT STEEP TEMPERATURE**

[40] elucidated the study conducted on argillite from 20°C to 25°C to report the consequence of temperature on the mechanical properties of argillite. The experimental investigation has been done by treating argillite samples with five different alkali solutions at 20°C, 40°C, 60°C, 80°C and 95°C. The weight and humidity of the samples were taken into account. Three tests tri-axial compression, micro-indentation and mini compression were carried out to estimate the effect on the mechanical properties. The stress-strain curves with pressure of 5 and 15 MPa were obtained from tri-axial compression test for 20°C, 60°C and 95°C. Some non-linearity occurs before and later the highest stress point. It is suggested that the effect of temperature has less effect as the pressure increase thus heading towards the termination of the micro-cracks formed due to increase in temperature.

From micro-indentation test, it has been found that at greater humidity, the elastic modulus shows sharp declination with increase in temperature and for lower humidity rate, the elastic modulus first declines and then increases with increase in temperature. And also due to the increase in temperature, the axial strain at the stress crest decrease. Hence increase in temperature or humidity results in the degradation of the mechanical properties which can be avoided by coupling effects. The study disclosed that due to temperature variations, there was a decline in their mechanical properties.

[41] interpreted the consequence of alkali solution on argillite at different temperature and time. The addition of sand, adsorbent clay and lime lead to the development of shear strength but constant

circulation of alkaline solution facilitates the development of cementitious mixture which is a very tedious process. [42] Thermal loading on Callovo Oxfordian argillite was done for the power ratings 277W and 925W. At the time of experimentation, argillite displayed notable change in its volume and exhibited a heavy pressure reaction that greatly affected the mechanical properties of argillite.

[43] pointed out the modifications in the argillaceous rock properties when exposed to a temperature from 80°C-21°C. At the time of investigation no visible damage was observed on the porosity and potential. [44] conducted a series of experimentation in Meuse Haute/ Marne argillite at various temperature and saturation degree. At 90°C and 85°C, the argillite samples were completely damaged due to swelling effect. The uniaxial resistance of argillite under compression contracted at higher humidity. From micro indentation test, it has been found that the elastic modulus and modulus of bulk compressibility decreased with the increase in temperature. The nuclear waste releases enormous amount of heat (80°C) that modifies the nature and structure of the argillaceous rocky material.

### **6. IMPACT OF HIGH TEMPERATURE ON MECHANICAL PROPERTIES OF GLASS**

When the temperature decreases, the yielding toughness increases whereas the strain decreases and flexible material changes to fragile material at 100K [45]. For 100°C, the properties such as tensile strength, compressive strength and toughness got increased nearly by 21%, 19% and 16% respectively rather than the samples exposed to room temperature [46]. And above 100°C, naturally the mentioned properties get declined by 25% and exposing to 520°C for 10 hours may decline its properties to 35% and exposure of glass to temperature above 520°C results in deformation of the substance.

During the exposure of glass components to quick temperature alterations, due to difference in temperature and thermal coefficient of expansion, stress occurs. Also stress occurs at the time of laminating two or more glass materials with different thermal coefficient of expansion. [47] explained the impact of consolidation temperature at 300°C and 250°C and revealed that consolidation

temperature has no impact on the grain intensity of the metallic glass. [48] elucidated the degradation of elastic modulus of glass and carbon glass at 250°C at 26% and 9%. Further the tensile strength of the two materials was declined to 31% and 35%.

[49] studied the issues related to the exposure of glass fibres reinforced polyamide mixture to moisture content. From the experimental investigation it has been concluded that the yield, flexural and tensile strength started to decline in the initial stage and remained constant afterwards. [50] related the response of different substrate temperature of 293K to 493K of a glassy film made up of zirconium, copper, nickel, aluminium, hafnium and titanium and estimated that the higher the substrate temperature lesser will be thermal consistency, toughness and anti-oxidation.

[51] presented the fallout of strength and rigidity of glass and glass carbon epoxy. From the experimental procedure, it has been found that the strength and rigidity of both the materials continued to decline till the maximum temperature of 110°C. [52] From 20°C to 120°C the young's modulus and breaking strength due to tension on fibre reinforced polyamide compressed due to rise in temperature whereas there is increase in breakdown strain during the temperature rise. A critical temperature below which the crystallized glass gets transformed into precipitate was explained [53]. The opposition to compression and plasticity incremented just after the boost in cast voltage to 9kV. [54] For a duration of 2 hours, glass fibre reinforced polymer samples were freeze continuously at 20°C and de-frosted at -10°C for 20 minutes followed by constant cooling or heating for 40 minutes. Sudden increase in the temperature of glass leads to cracking at the edges owing to the occurrence of unstable heat stress in the material.

### **7. EFFECT OF TEMPERATURE ON CERTAIN PHYSICAL PROPERTIES**

[55, 56] At 1000°C, cracks develop through individual granite crystals and at 800°C inter crystalline cracking takes place. The bulk density of the granite exhibited a negligible change at elevated temperature and the ability of the ultrasonic waves to pass through the granite decreased. When exposed to high temperature in the range of 800°C the granite crystals gets converted and the acoustic

emission of granite declines with respect to the temperature rise. [57] When exposed to high temperature of 650°C for 4 hours, numerous pores progressed on the clay structure. Subjecting clay bricks to 900°C leads to the formation of pores, thereby increasing the water absorption capacity of the bricks to a certain extent and above 900°C water absorption capacity decreases. Also increase in temperature cause the loss of weight of the brick. The colour of the brick gets transformed at elevated temperature (1200°C).

When kaolinite is heated (1200°C), it gets transformed into quartz, sillimanite and cristobalite of which cristobalite crest increases sharply at high temperature. This leads to the reduction in water absorption capacity of clay. Immediately upon the heat treatment (850°C) of ceramics based on clay, pores arise leading to increase in the volume of the ceramics. In addition to this, the heat transfer capacity of the clay got reduced after the heat treatment. The continuous heat treatment and sprinkling of water on clay bricks, alters the morphology and resistibility of the brick. [58, 59] At first heat conductivity and diffusivity of glass increased from room temperature to 160°C, reached to maximum value and then started to decrease at higher temperatures.

### **8. ALTERNATIVE WAYS TO ENHANCE THE STRENGTH**

- [60] The clay brick can be burnt at high temperature (700-1100°C) in order to increase its mechanical strength.
- Nanoclay can be used along with flax fabric to advance its strength.
- Starch and clay can be blended together to provide better mechanical strength.
- Clay can be made to react with epoxy to develop a physical interface thereby raising the mechanical properties.
- With the reduction of temperature, the elastic modulus and compression strength of frigid saturated clay can be increased.
- Nano silica added with waste glass enhances the consistency, flexural strength, and self-cleaning properties of glass material [61].
- [62] Nano particles of silicon dioxide together with basalt fibres improve the mechanical properties of basalt fibres thereby making it stronger.

- Granite can be combined with graphite in epoxy mixture to enhance its tensile strength.
- Strength of basalt can be enriched by using basalt at 50°C after the curing practise.
- Adding sufficient quantity of lime to argillite can boost up its mechanical properties by the condensation of the cementitious elements.
- Glass fibres when added with naturally modified clay exhibited better thermal and fire properties when compared with ordinary glass fibres [63].
- Glass specimen can be filled with nanoclay particles to intensify its strong modulus.
- Presence of some quantity of moisture can improve the strength of the glass supported with nylon 6/12.

### 9. CONCLUSION

Literature study reveals that elevated temperature have considerable effects on the mechanical properties of the analysed materials. Properties like compressive strength, tensile strength, permeability, elastic modulus, etc. decreases with increase in temperature. Furthermore, heating of materials alters their physical properties also. From the study, it is found that although all the materials undergo transformations in high temperature, granite and clay can withstand high temperature. Meanwhile, argillite and glass is more suitable for low temperature applications. It is therefore recommended to use the materials within certain temperature range and also with the addition of other materials to enhance the strength. Future investigation can be carried out to expel more appropriate materials to be synthesized with granite/ clay/ basalt/ argillite/ glass in order to utilize these materials at high temperature applications provided with good strength.

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