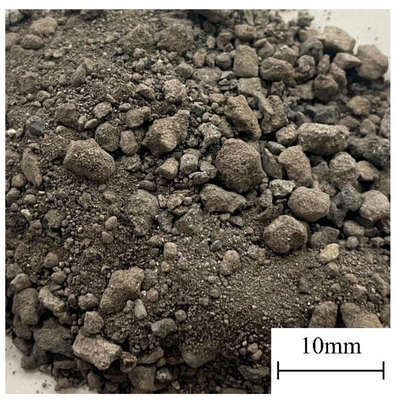
Triaxial compressive properties of steel slag with hydraulic hardness

水硬性を持つ製鋼スラグの三軸圧縮特性

Steel slag is a by-product generated during the iron and steelmaking process—specifically, during the reduction and refining stages in which iron ore is converted into steel. It can be broadly classified into **blast furnace slag**, produced during the melting and reduction of iron ore, and **steelmaking slag**, generated in the steel refining process. Due to its excellent mechanical properties, steel slag has attracted attention as a sustainable material that can replace natural resources and cement, contributing to energy and resource conservation as well as CO_2 reduction. Among them, steelmaking slag contains high amounts of **free lime** (CaO) and **free magnesium oxide** (MgO), which react with water and cause expansion. This hydration-induced expansion poses **a long-term stability challenge** when using steel slag as a ground improvement material. This study aims to promote the effective use of steelmaking slag in ground improvement by investigating changes in its mechanical properties due to hydraulic hardness. Through triaxial compression tests and elastic wave velocity measurements, the research seeks to elucidate the mechanisms of mechanical and volumetric changes associated with the hydraulic hardness behavior of steelmaking slag.

鉄鋼スラグとは、鉄鋼製品の製造工程（鉄鉱石から鋼を作り出す還元・精錬段階）で生じる副産物であり、高炉で鉄鉱石を溶融・還元する際に生成する高炉スラグと、製鋼および精錬プロセスで生成する製鋼スラグに大別できる。その優れた力学特性から注目されており，天然資源やセメントの代替材として、省エネルギー・省資源、CO_2削減に貢献するサステナブル資材として認識・利用されている。そのうち、製鋼スラグは、高含有の**遊離酸化マグネシウム**（MgO）および**消石灰**（CaO）が含まれており，これらの成分は水と反応することで膨張し、**長期的な体積安定性**が地盤改良材としての利用上の課題になる。本研究では、製鋼スラグの地盤改良材としての有効利用を目指し、三軸圧縮試験と弾性波速度測定で、水硬性による製鋼スラグの力学特性の変化について検討し、水硬性に伴う製鋼スラグの力学・体積変化のメカニズムを解明することを目的とする。ここでは三軸試験結果について報告する。



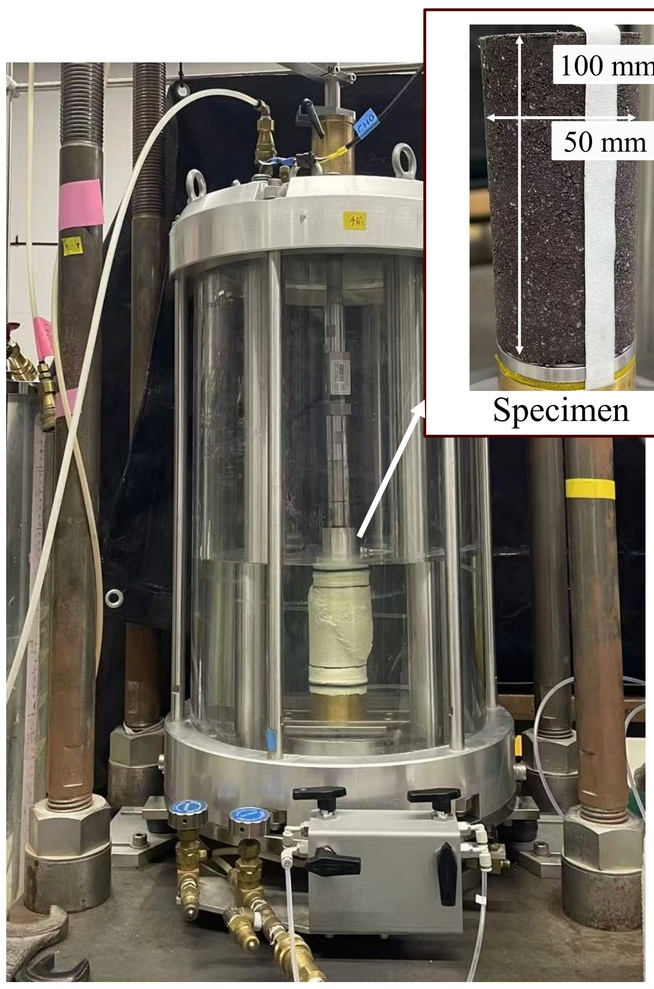
Steelmaking Slag

BFSFP

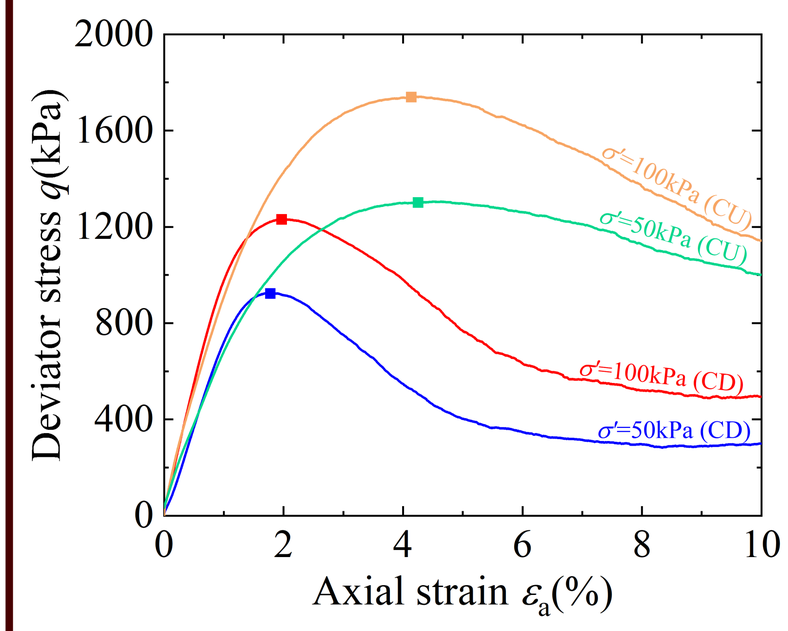
This study investigates the shear behavior of steelmaking slag-treated soils under consolidated drained (CD) and undrained (CU) conditions. The material used is the mixture of steelmaking slag and BFSFP (Blast furnace slag fine powder), in mass ratio 96:4. The results from triaxial compression tests on 3-day cured steel slag shows that:

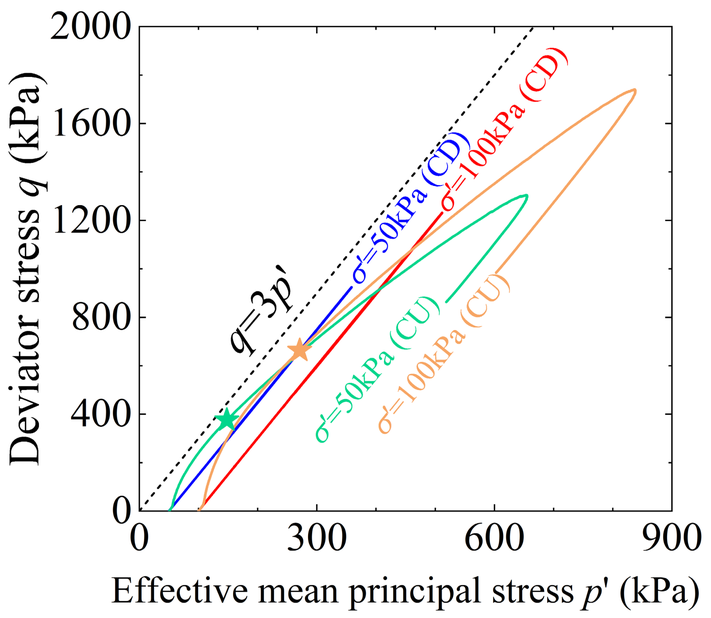
In CD conditions, the internal friction angle is approximately 45°. Under CU conditions, specimens initially follow the tensile cut-off line ($q=3p'$), where $\sigma'_3=0$, indicating shear-induced stress development at nearly constant mean effective stress. The maximum stress ratio (R_{max}) was identified by the peak points marked on the stress paths. Notably, the 3-day cured specimens did not reach the tensile cut-off line, suggesting incomplete hydration and insufficient solidification of free CaO/MgO. This highlights the importance of curing time in achieving stable mechanical performance. Further investigation using longer curing durations is required to evaluate long-term stability.

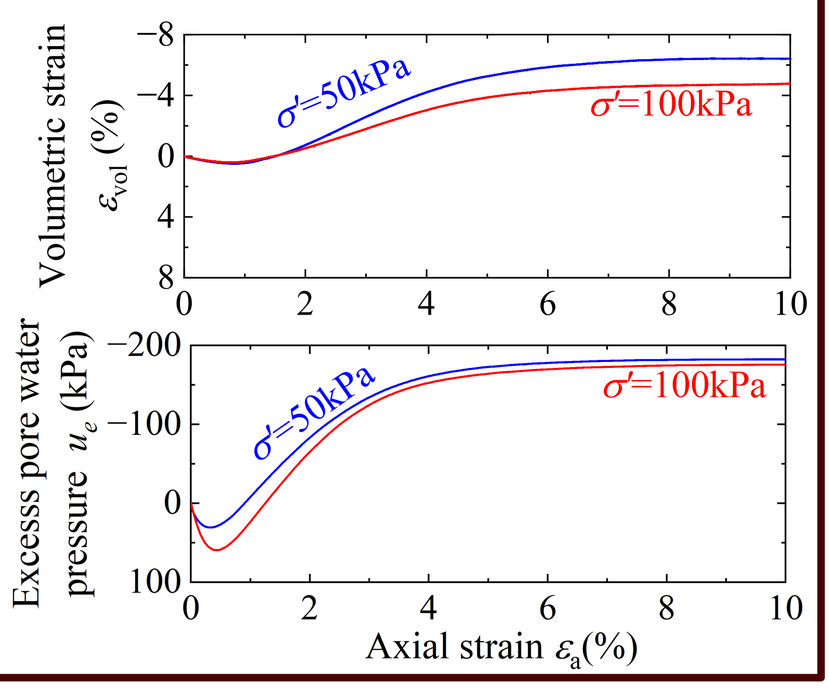
Furthermore, steel slag shows negative then positive dilatancy in CD tests, with volume change stabilizing at 6–8% axial strain. In CU tests, negative excess pore pressure develops early, increasing effective stress and undrained strength. Also, the pore pressure stabilizes around -180 kPa without signs of cavitation, indicating stable undrained behavior even at high suction levels.



Triaxial compression test machine







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