# Reactive MgO and Self-healing Microcapsules for Enhanced Well Cement System Performance


**Wenting Mao**

Department of Engineering

University of Cambridge


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# Abstract

The annular cement sheath plays a crucial role in ensuring well integrity by providing adequate zonal isolation, stabilizing the formation, and protecting the casing from corrosion. A majority of well integrity problems originate from oil well cement shrinkage and shrinkage-induced cracking, as well as cracking induced by other external stresses. The addition of expansive additives is a commonly used way to compensate for shrinkage. Compared to conventional ettringite-based and CaO-based expansive additives, MgO has many advantages including a thermally stable hydration product, relatively low water requirements for hydration, and designable expansion properties. These make MgO a promising candidate for delivering the desired expansion under the complex and variable underground wellbore environment. Self-healing materials which have the capability for autonomous crack repair are an attractive solution to addressing cracking problems in oil well cement. Engineered additions of healing agents for autonomic self-healing via a delivery system have been reported as effective ways to promote self-healing in cementitious materials. Microcapsules that can be easily added to cement pastes and dispersed through the cement matrix are considered particularly suitable for use in oil well cement. This research project investigates the efficacy of reactive MgO expansive additives to reduce shrinkage, and of sodium silicate microcapsules to improve the self-healing properties of oil well cement, and explores the feasibility of their combined use in a high temperature oil well environment.

Three types of reactive MgOs from different reactivity grades, high reactivity N50, medium reactivity MAG-R, and low reactivity 92/200, were characterised in terms of their expansion characteristics in cement paste prisms cured in water, and further tested on their autogenous shrinkage reduction at 80°C. The highly reactive N50 could only partially compensate for autogenous shrinkage, while the less reactive MAG-R and 92/200 completely compensated for autogenous shrinkage. MAG-R and 92/200 also showed effective drying shrinkage reduction at 90% RH. The restrained expansion of MAG-R and 92/200 during an early age was found to significantly improve the cracking resistance of oil well cement. The free expansion of 92/200, with low reactivity, caused significant strength reduction, but under restrained conditions the effect was mitigated as its compressive strength was enhanced by confined expansion. The addition of MAG-R increased compressive strength under both free and restrained conditions.

Two groups of sodium silicate microcapsules, T1 with rigid polyurea shells and T2 with rubbery polyurea shells, were characterised in terms of their thermal stability, alkalinity resistance and survivability during cement mixing, and the results verified their suitability for use in oil well cement at the high temperature of 80$^{o}$C. The effects of the two types of microcapsules on the self-healing performance of oil well cement at 80$^{o}$C were monitored using a variety of techniques. Oil well cement itself showed very little healing capability when cured at 80$^{o}$C, but the addition of microcapsules significantly promoted its self-healing performance, showing reduced crack width and crack depth, enhanced tightness recovery against gas permeability and water sorptivity, as well as strength recovery. Microstructure analyses of the cracking surface further verified the successful release of the sodium silicate core and its reaction with the cement matrix to form C-S-H healing products. Both groups of microcapsules showed comparable self-healing efficiency. Their different shell properties mainly influenced the strength of oil well cement, with rigid shell microcapsules causing less strength reduction than rubbery shell microcapsules.

The overall performance of oil well cement containing both reactive MgO and microcapsules were evaluated. The combined addition of MgO MAG-R and T1 microcapsules showed similar expansion performance and self-healing efficiency compared to their individual use. The use of MgO MAG-R compensated for the strength reduction caused by the addition of microcapsules, achieving an overall improvement in the cement strength.