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MECHANICAL TREATMENT OF AGGLOMERATED $Ca(OH)_2/CaO$ PARTICLES DURING THERMAL ENERGY STORAGE REACTIONS

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1. ABSTRACT

The reversible reaction of $CaO/Ca(OH)_2$ for thermochemical thermal energy storage systems has shown great potential for applications in concentrated solar power (CSP) plants. However, the reversibility of the reaction is still lacking due to many factors, one of them is the formation of agglomeration. This paper aims to investigate the effectiveness of mechanically crushing of agglomeration after each cycle on the efficiency and stability of the reaction. It has been found that crushing of agglomeration had led to a more stable powder bed, more loose powder with a larger surface area, which increased the generated heat, and the captured CO_2.

2. INTRODUCTION

A Thermal Energy Storage (TES) system has recently become crucial for Concentrated Solar Power plants to store energy during the day and utilize it when sunlight is weak or non-existent. Multiple TES technologies, such as sensible, latent, and thermochemical, are available. The Thermochemical Thermal Energy Storage (TTES) system has the highest potential since it has a theoretically unlimited storage period and a minimum heat loss, but it has the least maturity among the other types. The reaction of $Ca(OH)_2/CaO$ is one of the most promising TTES reactions due to its nontoxicity, reversibility, independence of a catalyst, the high availability with low price of the product, and having working temperatures that match those needed for concentrated solar power plants. The reaction starts with the dehydration of $Ca(OH)_2$ by supplying heat to it and breaking it into CaO and steam, while the reversible reaction (hydration) occurs when steam is supplied to CaO and heat is generated. However, one of the major problems affecting the reaction is the occurrence of particle agglomeration within a few hydration and dehydration cycles, which decreases the total powder surface area, reduces the reaction kinetics, and decreases the overall efficiency of powder conversion. The aim of this research is to investigate the effectiveness of mechanically crushing agglomerated particles after each hydration and dehydration cycle in comparison to another set where no mechanical treatment has occurred.

3. METHODOLOGY

The methodology of this research is to increase the efficiency of the $CaO/Ca(OH)_2$ heat storage by mechanically crushing the agglomeration. To test this hypothesis, an experiment involving two samples was conducted with one sample going through mechanical crushing after the end of each cycle, while the other went through the cycles without any intervention. For one cycle to be completed a dehydration and hydration steps must be completed, as follows:

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1- Dehydration (endothermic reaction) at 600℃ for two hours for 70 grams sample of $Ca(OH)_2$:

$$Ca(OH)_{2\,(s)} + Heat \rightarrow CaO_{(s)} + H_2O_{(g)}$$

2- Hydration (exothermic reaction) of CaO at 200℃ (to prevent condensation of water) with steam of 8.5 ml/min.

$$CaO_{(s)} + H_2O_{(g)} \rightarrow Ca(OH)_{2\,(s)} + Heat$$

After the hydration step (i.e. the end of the cycle), the crushed set goes through mechanical crushing to destroy the agglomeration that has formed during the cycle.

4. RESULTS

It has been noticed that for the uncrushed set, although no intervention has occurred, the formed agglomeration would break down naturally by themselves to smaller agglomeration with the progression of cycling. This behavior could be explained by the fact that with each hydration step, the size of CaO particles increases by absorbing H_2O to become $Ca(OH)_2$, while during the dehydration step the H_2O is removed and the size of particles decreases again. This repeated behavior of size growth and diminished leads to structural damage in the agglomerates. Figure 1 compares the powder bed after six cycles of crushed and uncrushed sets, to the powder bed after one cycle. It can be noticed that for the uncrushed set, almost no powder can be seen, and the number of small agglomerations is much higher than that of the crushed set where only one big agglomerate can be seen surrounded by loose powder.

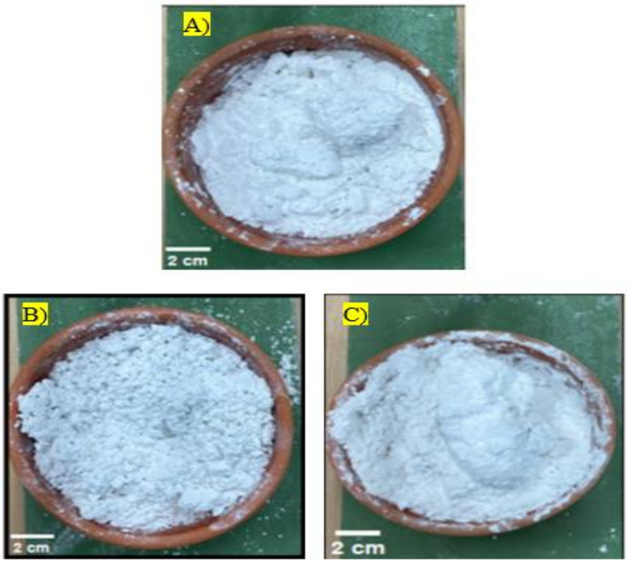

Figure 1: Agglomeration after (A) the first cycle, (B) the sixth cycle of the uncrushed set, and (C) the sixth cycle of the crushed set

The different morphology of the formed powder beds had a great effect on the reactivity of the powder to the surrounding environment. First, in terms of the generated temperature, Figure 2 shows the behavior of the crushed and uncrushed sets. It can be seen that the crushed set showed better performance up until cycle 4, where one big agglomerate in the uncrushed set broke down naturally exposing the entrapped CaO particles to react with the incoming steam, and consequently, generating high temperatures. Also, it can be noticed that the generated temperature showed a decreasing trend the generated temperature, this could be attributed to the fact that the available CO_2 in the environment reacted with CaO particles producing $CaCO_3$. The problem with calcium carbonate is that it needs temperatures higher than 750 C to break down to CaO and CO_2, which means the more cycles the powder goes through, the more $CaCO_3$ is created that gets carried out through the cycles without reacting. Figure 3 shows the percentage of $CaCO_3$ in the crushed and uncrushed sets concerning the cycle number. The loose powder available in the crushed set meant more CaO particles were exposed to CO_2, which led to higher percentages of $CaCO_3$ in the crushed set. Interestingly, both sets had the same amount of $CaCO_3$ with the progression of cycling.

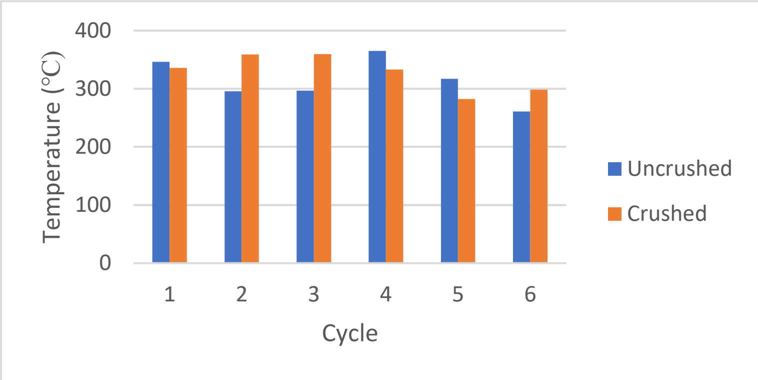

Figure 2: The generated temperature during the hydration step from the uncrushed and crushed sets

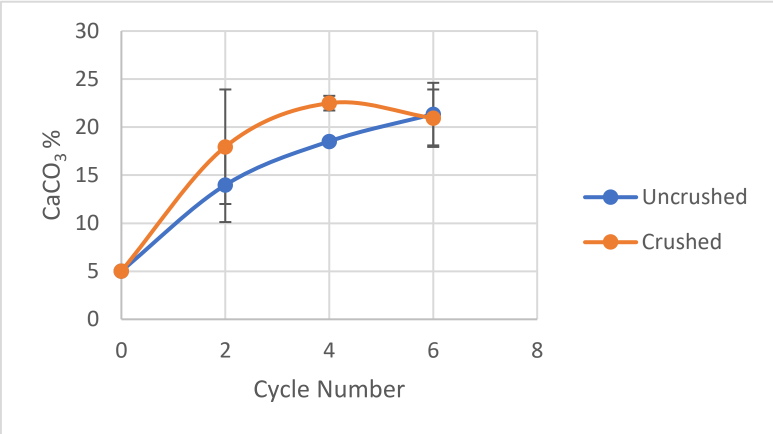

Figure 3: Calcium Carbonate percentage in the powder bed of the crushed and uncrushed sets

5. CONCLUSIONS

It can be concluded that crushing of agglomeration after each cycle clearly affected the morphology of the produced powder bed with more loose powder available for reaction than the case of no crushing. This loose powder meant more surface area and more particles are available for the reaction, which increases the efficiency and repeatability of the reaction. In fact, higher temperatures were generated from the crushed set compared to the uncrushed set. However, more carbon dioxide was captured by the crushed set compared to the uncrushed set especially in the first two cycles.

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