Morphology and Residual Strength of Modified Single Component Sodium Silicate Bonded Sands.

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ABSTRACT

An increased number of foundries are exploring the use of inorganic binders due to their environmental friendliness and excellent foundry properties. This paper investigates the residual strength of a new type of single component sodium silicate binder and the relationship of the residual strength to the morphology of the bond as revealed by scanning electron microscopy (SEM). The sodium silicate binder was mixed at 3% and cured by three different methods including heat, carbon dioxide and ester. The residual strength of all the curing mechanisms with the same base silica sand showed a drop in strength from the as cured temperature up to a temperature of 800 ^{0}C (1472^{0}F) and then a secondary peak at 1000 ^{0}C (1832^{0}F). SEM image analysis of the bonds provides an in depth understanding of the trend in residual strength.

Keywords: Inorganic, foundry, binders, bond, silica sand, bond morphology.

INTRODUCTION

Water glass, being a water solution of sodium silicate, has been used in the foundry industry for over sixty years for manufacture of mould and core moulding sands. Along with technical progress and widening knowledge on this inorganic binder, many hardening methods of it containing moulding sands were developed, including blowing with carbonic anhydride in the CO_2 process and drying with air at higher temperature [1] .The advantages of using inorganic binders are as follows reduction of odour emission during moulding and core making, low emission of fumes during the pouring process, no emission of noxious materials, low level of condensates in the die, and reduced gas behaviour [2]. The inorganic binder is a cheap material, environmentally harmless and neutral for the foundrymen in contact with it. Hardening moulding sands with inorganic binders is fast and a technologically simple process by making use of CO_2 and both traditional and conventional drying methods [1].

Water glass owes its properties to hydration, hence the process is considered from a physiochemical point of view as the reaction of the dehydration of the colloidal solution, resulting in the formation of a base phase gel [3]. Dehydration curing of the silicate binder in a foundry sand takes place when there is sufficient heat to evaporate the free water from the silicate solution[4].

The use of hot air to dry the binder has the effect of providing a uniform set of the binder without limiting its bench life [5].The hot air process achieves high and uniformly distributed strength over the entire cross section of the core. Thin and thick parts are equally cured [6]. It becomes clear why sodium silicate bonded cores which are hardened by means of carbon dioxide do not achieve the theoretically possible maximum strength, because the water in the binder is not removed [7]. Moulding sands with water glass hardened in the CO_2 process, in which bonding bridges and binder coat are exfoliated and cracked, are characterised by the lowest strength ` [1].The ester process uses much less amounts of hardener which are organic processes. The hardener is between 8-12% and releases few harmless emissions during pyrolysis at pouring. The moulds produced with this process produce comparable strengths to the furan process [6].Hardening with esters is widely applied in industry, among others because of its relatively good strength parameters and of easy dosing the liquid hardener [8]. The ester process has a strong homogenous bond at 200 ^{o}C (392^{0}F) when the temperature is at 400 ^{o}C (752^{0}F) holes begin to form due to the loss in water of crystallization, the holes continue to increase up to 600 ^{o}C (1112^{0}F), however at 800 ^{o}C (1472^{0}F) the glass phase formation starts and this behaviour could be the explanation of a drop and then increase in strength of the sodium silicate binders [9]. Kohler's theory suggests that rapid dehydration to reduced condensation degrees causes lower strengths which is contrary to economic aspects. At 200 ^{0}C the adsorbed water, the water molecules attached to the silanol groups – (Si-OH) through hydrogen bonds is removed. With increasing modulus the drying times decrease as well as the residual water contents [6]. The Si-O-Si linkage, which is called a siloxane linkage, is the only bond which imparts rigidity to the bonded sand grains. This bond is far stronger than either the Na_2CO_3 bond or the hydrogel bond when cured with the CO_2 gas process.

METHODOLOGY

Three silica sand collected for moulding was from the philippins area in the Western Cape of South Africa. The silica sand is from springfontyn formations and consist dominantly of sub-rounded grains.

The bending strength test specimen were produced by mixing 3% of sodium silicate binder by weight of silica

sands. The mixed sand was cured by three different curing methods. The methods used and the reason for selection are listed below.

- Carbon dioxide curing; this is a widely used curing method for making cores and moulds and
- Ester curing; this method is a self-hardening no bake process widely used in the production of moulds and large cores.
- Heat curing; it is also referred to as the warm box process is a widely used method in the production of cores in a modern environmentally friendly manner.

Table 1 shows the curing parameters used to cure the sands

Table 1: Curing parameters

Curing for residual strength evaluation			
Curing method	*Carbon dioxide*	*Ester curing*	*Heat curing*
Parameters	Flow rate 5 litres/ minute	10 % hardener	3.3KW
Time	10 seconds	24 hours	300 seconds

The samples after curing were exposed to heat from 300^0C (572^0F) to 1200^0C (2192^0F). The test specimen were tested for strength on the universal strength machine. Thereafter the same samples on the broken plane had their bonds evaluated on the scanning electron microscope.

The bending strength is calculated as follows;

The patterns used for the test specimen, are a transverse 12 gangue core box and a transverse ramming accessories with the following dimensions 22.4 mm height X 22.4mm width X 172.5mm.

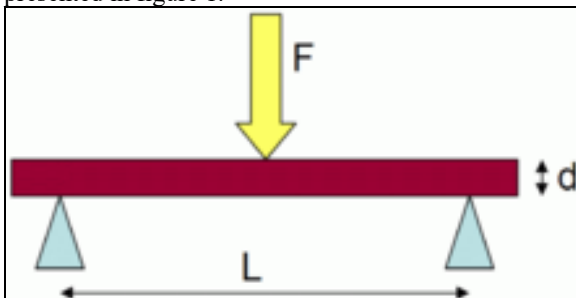The forces acting on the bending test specimen are presented in figure 1.

Figure 1: Bending strength diagram

Figure 1 shows a sketch of the forces acting on the test specimen.

$\sigma = 3FL/2bd^2$

F= load (force) at fracture point **(X)**

L= Length of the support span (150mm)

b = width (22.4mm)

d= is the thickness (22.4mm)

σ= Bending strength in N/cm^2

EXPERIMENTAL RESULTS AND DISCUSSION

EXPERIMENT 1: CARBON DIOXIDE CURED SAND.

Figure 2 shows the residual strength results for carbon dioxide cured sand samples. The results do not show indications of strength from 300 ºC (572 ^{0}F) to 800 ºC (1472 ^{0}F).
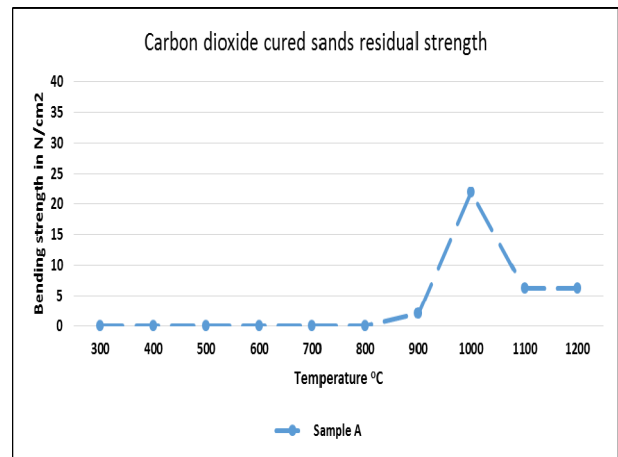

Figure 2: Carbon dioxide cured sand residual bending strength.

Rapid dehydration to reduced condensation degrees causes lower strengths because at 200 ^{0}C (392^0F) the adsorbed water, the water molecules attached to the silanol groups (Si-OH) through hydrogen bonds is removed [6] .This could be the likely reason for very much reduced strength.
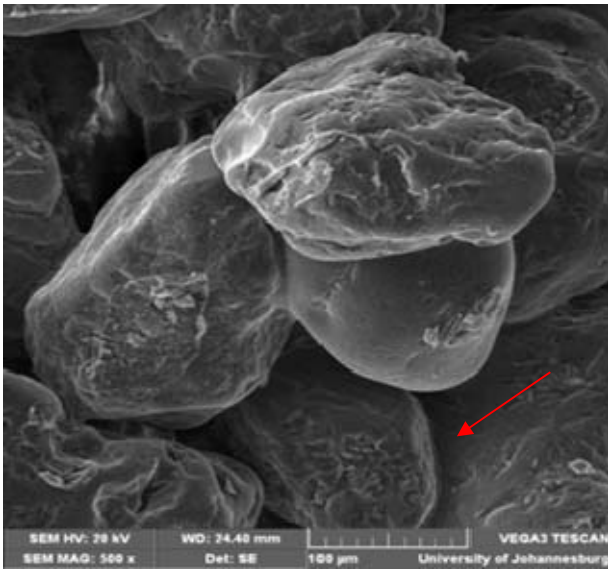
Figure 3: Carbon dioxide cured sand at 300°C (572°F)

The image in figure 3 shows that the carbon dioxide cured sand contains a bond which is homogenous but with fine cracks consistent with [1](Stachowicz, et al. 2010), but however the bond is almost homogenous and this could be due to further curing by heat in the process of heat exposure, however the strength of the homogenous bond is overcome by several fine cracks indicated by the red arrow.
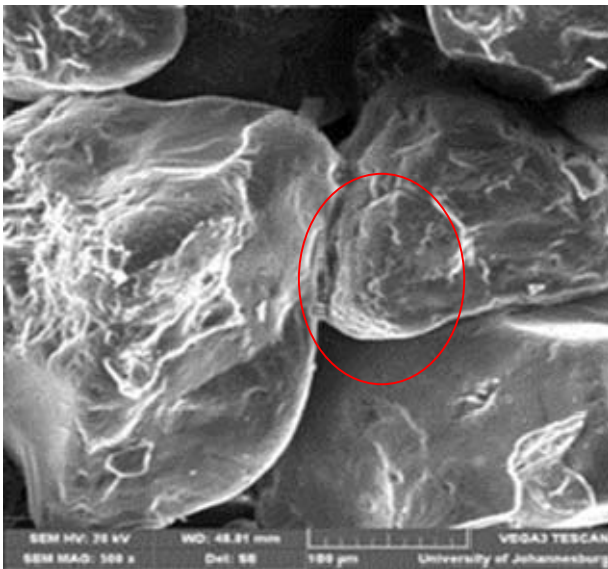

Figure 4: Carbon dioxide cured sand at 800 °C (1472 °F)

The image in figure 4 shows that the lowest residual strengths are accompanied with widening cracks in the encircled area of the carbon dioxide cured sand bond [1].
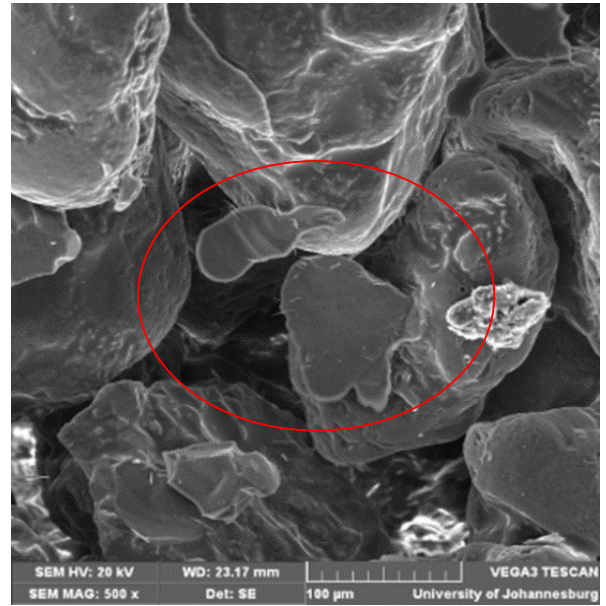
Figure 5: Carbon dioxide cured sand at 1000 °C (1832 °F) with flat and smooth bond cleavage

The image in figure 5 shows that the high secondary peak residual strengths are accompanied with the formation of the glassy phase. The glassy phase reconstructs the bond from the cracks and brings about a new binding strength [6]. The other notable feature is a flat and smooth bond fracture plane encircled in figure 5.
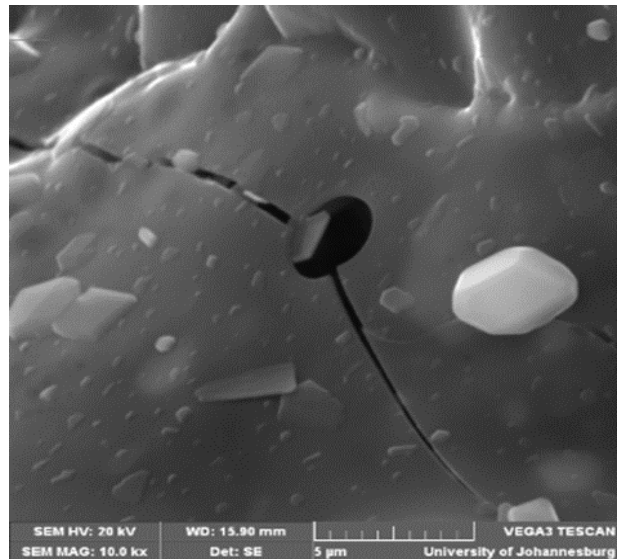

Figure 6: Carbon dioxide cured sand at 1200 °C (2192⁰F)

The image in figure 6 shows the structure of the bond at a higher magnification when the sand loses strength after the glassy phase. The images are characterised by cracks in between the bond for the carbon dioxide cured sand at higher magnification.
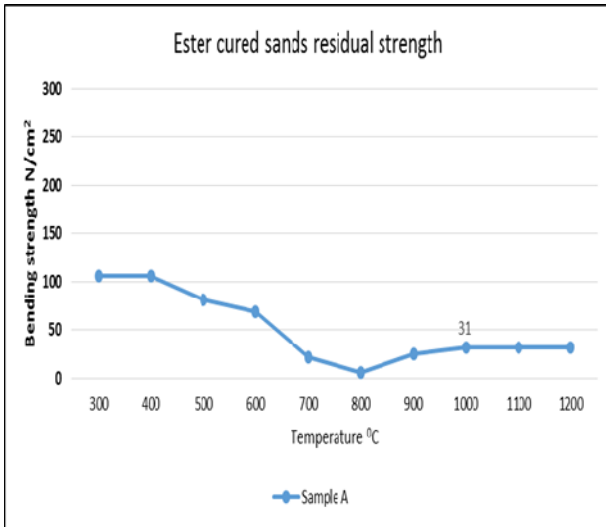
Figure 7: Ester cured sand residual strength

Figure 7 shows the residual strength results for ester cured sand samples. The results show a decrease in strength from 400°C (752 °F) to 800°C (1472 °F). The phenomenon behind the lowest residual strengths accompanied with a temperature of 400 °C (752 °F) is that the binder bridges begin to develop holes as presented in figure 6 which lead to reduced strength [9]. Rapid dehydration to reduced condensation degrees causes lower strengths because at 200 °C the adsorbed water, the water molecules attached to the silanol groups – (Si-OH) through hydrogen bonds is removed [6]. The silanol bond is usually the strongest bond in sodium silicate bonded sands.

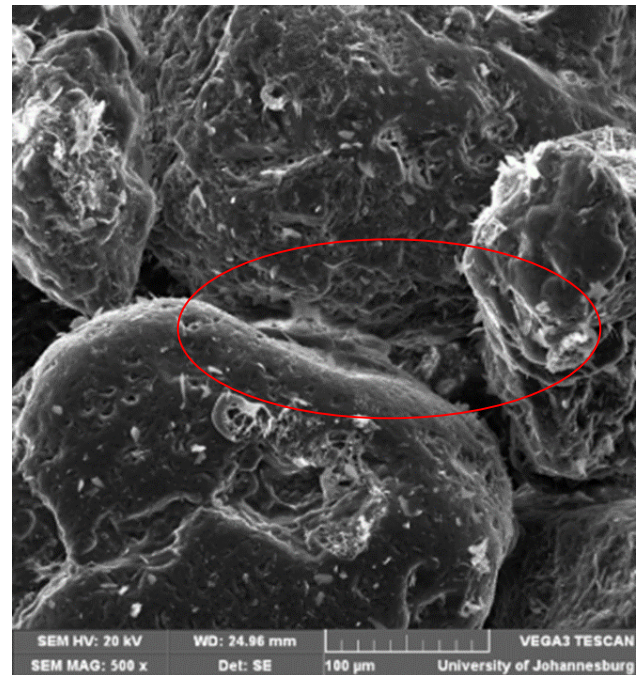
Figure 8 Ester cured sand at 300 °C (572°F)

Figure 9: Ester cured sand at 800 °C (1472 °F)

The ester cured sand at 800 °C (1472 °F) in figure 9 shows widening cracks and increased exfoliation on the bond at this temperature the sand is at its lowest strength.
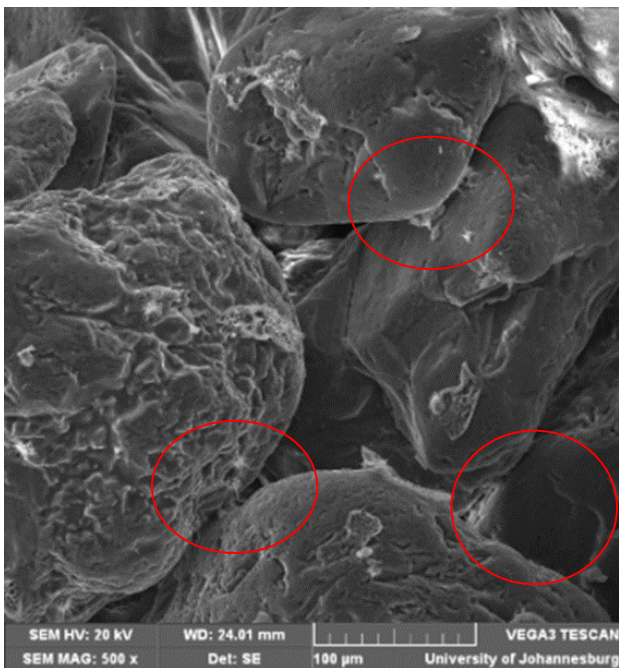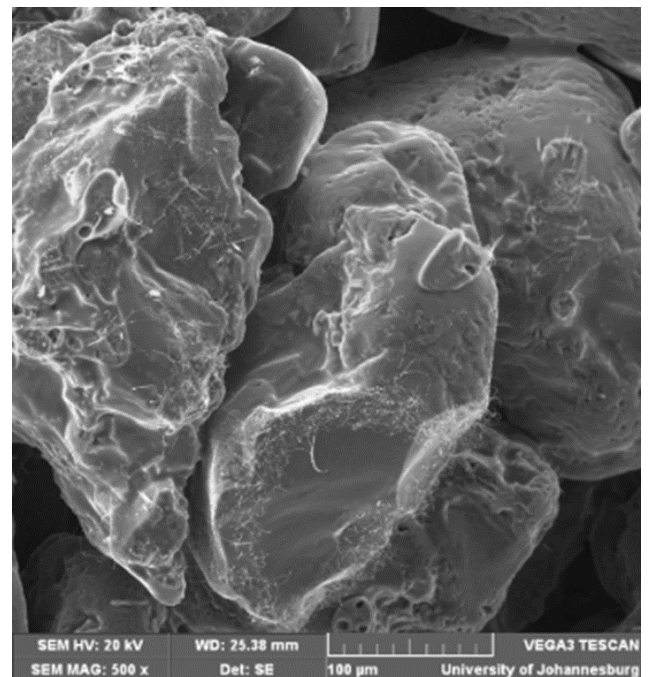

Figure 10: Ester cured sand at 1000 °C (1832 °F)

The strength peaks again at temperatures between 900 °C (1652 °F) and 1000 °C (1832 °F) at most 31 N/cm^2 (0.31 MPa). The highest strengths develop in areas which have been heated between 800 °C (1472 °F) and 1000 °C (1832 °F) due to the phenomenon of the formation of a glassy phase presented in figure 10. Water glasses begin to melt from 800 (1472 °F) 900 °C (1652 °F) depending on the modulus. When molten the water glass completely loses strength, upon cooling and solidification it gives the stubborn strength [6] .The structure of the sand grains and bond with the stubborn strength is presented in figure 10.
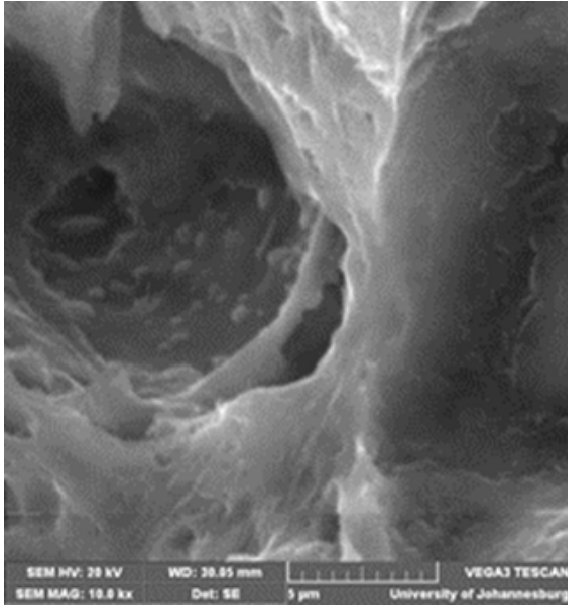

Figure 11: Ester cured sand at 1200 °C

The secondary peak does not drop with increased temperature up to 1200°C (2192°F). The peak is associated with the phenomenon of sintered material and glassy phase that remains soft and gummy after cooling as presented in figure 11.
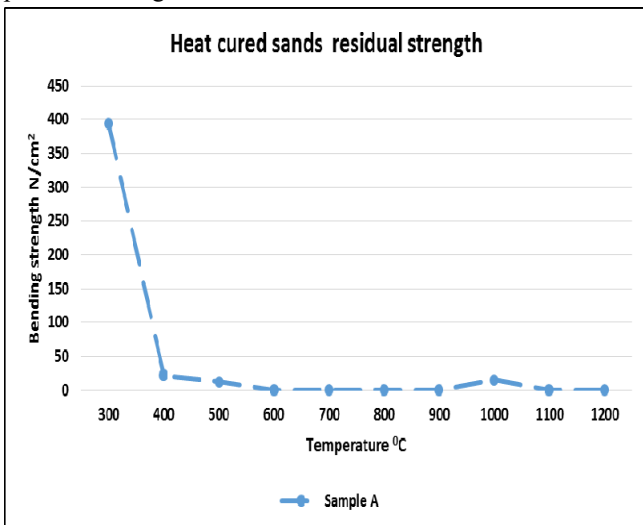

Figure 12: Heat cured sand residual strength

Figure 12 shows the residual strength results for heat cured sand. The sample shows a decrease in strength from 400 °C (752 °F)
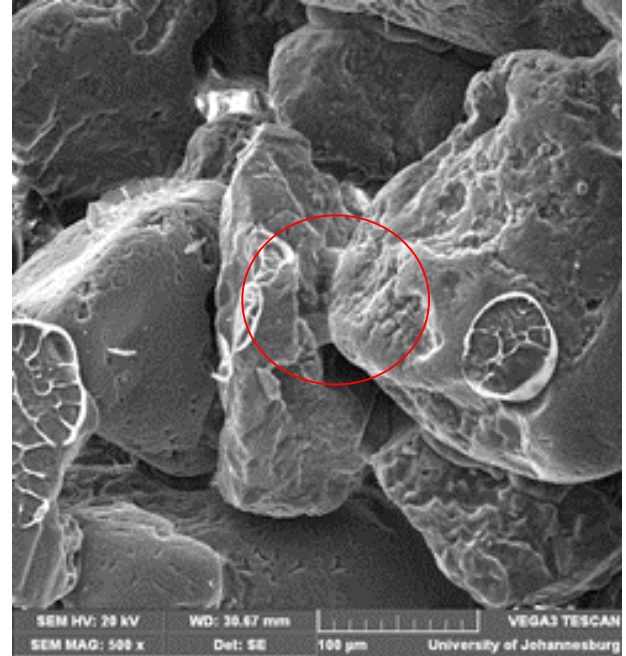

Figure 13: Heat cured sand at 300 °C (572°F)

The heat cured bond is more or less uniform and homogenous at 300 °C. The bond in figure 13 leads to high strengths shown at the given temperature in figure 12.There are more siloxane linkages which are stronger bond linkages thus the heat cured sand is capable of maintaining a homogenous bond at 300 °C (572°F).
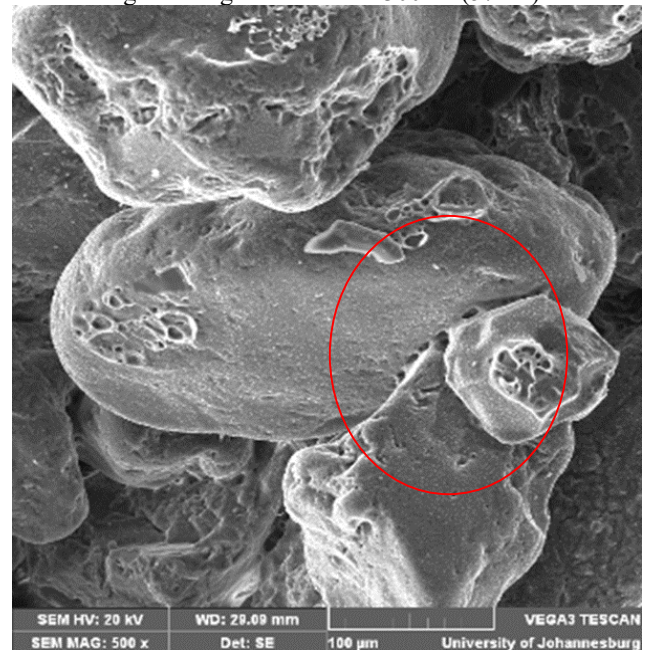

Figure 14: Heat cured sand at 800 ° C (1472 °F)

The heat cured sand sample completely loses strength between 600 °C (1112 °F) and 900 °C (1652 °F). The phenomenon behind the complete loss in strength is that the holes developed at previous temperatures become more and bigger at 600 °C (1112 °F) resulting in complete or almost complete loss in strength shown in figure 13 and 14.

Lower strengths are developed in the regions between 400 °C (752 °F) and 600 °C (1112 °F) as presented in figure 12.
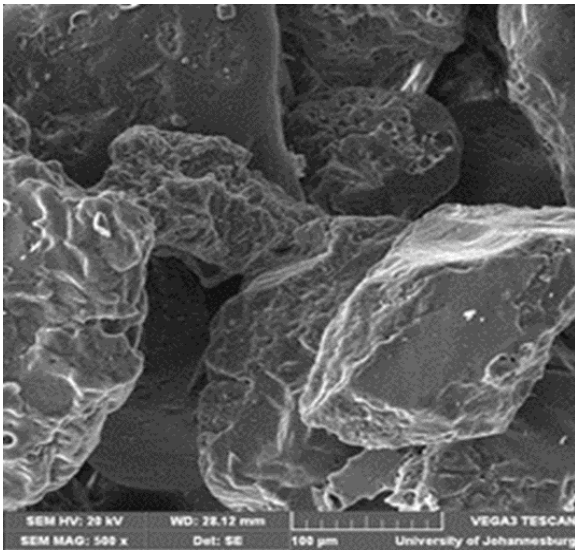

Figure 15: Heat cured sand at 1000 °C (1832 °F)

The heat cured sand sample peaks again at 1000 °C (1832 °F) both peaks are almost 31 N/cm². The highest strengths develop in areas which have been heated between 800 °C (1472 °F) and 1000 °C (1832 °F) due to the formation of the glassy phase. The phenomenon is that water glasses melt from 800 °C (1472 °F)-900 °C (1832 °F) depending on the modulus. When molten the water glass completely loses strength, upon cooling and solidification it gives the stubborn strength.
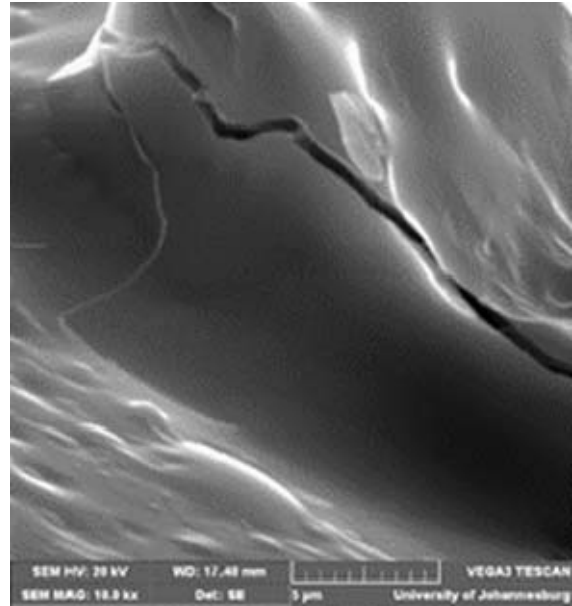

Figure 16: Heat cured sand at 1200 °C (2192⁰F)

completely to 0 N/cm2 (0MPa) with increased temperature. The drop is associated with sintered material stresses and associated cracking presented in figure 16 [6].

Figure 17: Heat cured plumbing cores

The cores presented in figure 17 were cured using heat at a temperature of 170 °C (338 ⁰F). The cores were produced in foundry using the same sodium silicate binder system.

CONCLUSIONS

The final strength of modified single component sodium silicate binders and the morphology of the bonds are related and similar to the morphology of sodium silicate binders to which the breakdown agents come as a second additive to the binder. The main mechanism responsible for the drop in residual strength is dehydration. The dehydration results in a morphology with holes that develop to become bigger as holes which eventually become cracks. The cracks continue to widen with increased temperature in low strength areas. The secondary residual strength peaks are associated with sintered material which is homogenous and glassy. The major difference in morphology is the ester cured sand which is gummy at 1200^0C (2192^0F) and maintains its secondary peak strength whilst the Carbon dioxide and Heat cured sands are dominated by huge cracks at the same temperatures leading to a drop in the secondary peak residual strength. The morphology of the bond is influenced by the exposure to temperature and the curing method used. Based on the strength results and collapsibility profile it would be ideal to use the carbon dioxide and heat cured cores and moulds in the casting of low melting point alloys because of their ability to quickly drop in residual strength. The use of ester cured cores and moulds will be better with high melting point alloys since it takes time to achieve low strengths, the low strengths are attained at higher temperatures. The most preferable cores are heat cured cores which can give a high strength and at the same time give lower residual strengths at lower temperatures thus allowing for better collapsibility.

ACKNOWLEDGMENTS

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