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Characterization of GMBOND® Sand Binder Process

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A. Tensile Strength Profile of GMBOND® Process

Several molding aggregates were used to determine the bonding properties, in terms of core tensile strength, of GMBOND® as a function of molding aggregate, binder level, and water content. Aggregates investigated were two silica sands (GFN 50 and GFN 55), two synthetic mullite (GFN 50 and GFN 60), zircon sand (GFN 86), two olivine sands (GFN 100 and GFN 120), and carbon (GFN 85). All molding aggregates were coated with 0.50%, 0.75%, and 1.0% GMBOND® binder, respectively. The screen distribution of the tested aggregates is provided below in the table showing the distribution and average grain fineness number. The amount of binder applied was based on the density of the molding aggregate. Varying amounts of water was utilized to simulate the effect of bench life of the binder. The information collected provides insight to the bonding characteristics of the GMBOND® binder for different molding aggregates and varying processing conditions.

Screen Distribution

Sieve Size	**W410** Percent	**W530** Percent	**LD50** Percent	**LD60** Percent	**Zircon** Percent	**Olivine** Percent	**Carbon** Percent
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.2	0.0	0.0	0.0	0.0	0.0	0.2
40	12.0	1.6	13.3	5.9	0.0	0.0	0.6
50	26.0	30.4	38.1	24.1	0.2	0.3	4.1
70	36.3	42.8	28.4	31.2	7.7	7.2	16.2
100	19.7	18.9	14.0	22.9	42.9	37.4	35.6
140	5.0	5.4	4.8	10.9	43.4	36.6	30.7
200	0.6	0.8	1.1	3.7	5.3	14.8	10.2
270	0.1	0.1	0.2	1.0	0.4	3.3	2.0
Pan	0.0	0.0	0.0	0.2	0.1	0.4	0.4
AFS GFN	**52**	**54**	**50**	**62**	**86**	**95**	**85**

Problem. Core tensile strength dependency of molding aggregates.

Objective. To understand the influence of varying binder levels and water content on a variety of molding aggregates to observe the influence of molding aggregate chemistry and grain shape.

Measurement system. The tensile strength of the GMBOND® cores was used to determine the maximum tensile stress as a function of time. AFS Procedure 329-87-S was used to determine the tensile properties of the cores. Samples were fractured at the intervals of 30 seconds, 5 minutes, 1 hour, 3 hours, and 24 hours from completion of processing cycle.

Experimental Procedure. All molding aggregates investigated were coated by Hormel Foods. The reported percentage of binder was based on the density of the sand. The table below shows the amount of binder per volume of molding aggregate. As a reference, silica sand was used as the standard for determining the percentage binder applied to the molding aggregates.

Sand	Density	Amount of Binder per Sand Density (g Binder/cm^3 Sand)		
		1.00%	0.75%	0.50%
Silica	1.61	0.0161	0.121	0.081
Zircon	2.80	0.0280	0.210	0.140
Mullite	1.55	0.0155	0.116	0.078
Olivine	1.76	0.0176	0.132	0.088
Carbon	1.12	0.0112	0.084	0.056

For each experiment, an approximate 3,000 g sample was obtained by splitting the total amount of coated sand. Depending on the experiment, the amount of water added to rehydrate the bio-based binder was determined based on the amount of binder on the sand. The tested molding aggregate was then placed into a Hobart mixer. Water was added during mixing and mixed for approximately 30 seconds. The bowl was removed and the sand flipped to bring any dry sand from the bottom of the mixing bowl to the top. The mixing bowl was placed back onto the mixer and mixed for another 30 seconds. After mixing, the tested sand dwelled for approximately one minute to insure complete absorption of the water into the binder. The sand was mixed again for another 15 seconds before transferring to the core blowing machine.

Dog bone cores were blown into the tooling for 0.5 seconds at 60 psi. The cycle time used was a 40 second activation dwell period with the tooling at 150^{o}C followed by a 40 second dry air purge at 40 psi. Dog bones were removed from the tooling and the time recorded. Tensile strength was recorded using a Twing-Albert tensile tester. Three tensile strength values were recorded for each time period and the average is reported in the report.

Discussion of Results.

A. **Silica Sand.** Two silica sands, W530 and W410, were used as baseline data for comparing the other molding aggregates in addition to assessing the influence of grain size and distribution and bench life. The first set of experiments used silica sand at 1.0% binder content and varied the water content to simulate binder bench life. Figure 1 shows the results on the influence of varying water content on tensile strength. For each silica sand, decreasing water content lowers the short term and long term tensile strength. Comparing to the baseline water content of 2.0%, a 15% reduction in tensile strength is observed when the water content drops to 1.75% and a 40% reduction is observed when the water content is lowered to 1.50%. Although the rate of water evaporation was not determined, it can be concluded from Figure 1 tensile properties of GMBOND® decreases with increasing bench life.

Figure 2 shows the tensile properties of the two investigated silica sands coated with 1.0%, 0.75%, and 0.5% GMBOND®, respectively. For all experiments, a 2:1 water to binder ratio was used. For both sands, decreasing binder content lowers the tensile strength. Using silica sand coated with 1.0% GMBOND® as reference, both W410 and W530 showed an approximate 46% decrease in immediate tensile properties when the binder content is lowered to 0.75% and a 33% decrease in 24 hr tensile strength. When the binder content is lowered to 0.5%, an approximate 70% reduction in tensile strength for all time periods was observed. It can be surmised tensile properties will decrease as the sand is reused without conditioning.

From Figure 1 and 2 grain size distribution appears to have an influence on bonding properties. Silica sand W530 with a GFN of 54 showed higher tensile strength than the W410 having a GFN of 52. This was observed for both the varying water content and binder content experiments. Because of the difference in average grain fineness number, higher tensile strength would be achieved from the increase in sand grain contact points for development of binder bridge morphology. The increase in grain fineness would result in a decrease in permeability. The decrease in permeability would be expected to influence the removal of water from the binder and decrease tensile properties. Surprisingly, this was not observed.

B. **Synthetic Mullite.** Two synthetic mullite aggregates, LD50 and LD60 supplied by Carbo Ceramics, were investigated. The first set of experiments used the mullite aggregate at 2.0% binder content with varying water content to simulate binder bench life. Figure 3 shows the results of the influence of varying water content on tensile strength. As previously discussed, decreasing water content degrades the bonding properties of GMBOND®. Comparing to the baseline water content of 2.0% for 24 hr tensile strengths, an approximate 15% reduction in tensile strength is observed when the water content drops to 1.75% and a 25% reduction is observed when the water content is lowered to 1.50%. The reduction in tensile strength for 1.75% was similar to that observed with silica sand. However, the reduction in tensile strength was not as great when compared to silica sand. Lower water content showed a slight increase in immediate tensile strengths. This observation could be attributable to the higher permeability of the synthetic mullite by improving the dehydrating process of GMBOND®.

Figure 4 shows the tensile properties for the low density mullite aggregate coated with 1.0%, 0.75%, and 0.5% GMBOND®, respectively. All experiments used a 2 to 1 water to binder ratio. For both aggregates, significant reduction in bonding properties was observed. Using the 1.0% GMBOND® coated aggregate as reference, both LD50 and LD60 showed an approximate 27% decrease in immediate tensile properties and a 40% decrease in 24 hr tensile strength when the binder content is lowered to 0.75%. When the binder content is lowered to 0.5%, immediate tensile strength properties decreased approximately 55% with a 70% decrease at 24 hr. Comparing to silica sand, the percent reduction in bonding properties at 0.75% GMBOND® was lower for immediate strengths but slightly higher for the 24 hr. tensile strengths. At 0.5% GMBOND®, immediate bonding properties for the mullite material was not a great as that observed with silica sand. 24 hr tensile strength showed similar percent reduction in bonding properties as silica sand. It is suspected that the higher permeability of mullite aggregate assists in the initial drying of the binder.

The synthetic mullite aggregates used in the experiments had similar grain distributions as the silica sand. The LD50 aggregate distribution was comparable to the W410 silica sand and the LD60 aggregate distribution similar to the W530 silica sand. Comparing the mullite aggregate to silica sand shows equivalent bonding properties at all investigated time periods, water content, and binder content. As observed with silica sand, the LD60 material had better bonding properties than the lower GFN LD50 aggregate. This supports the hypothesis that higher number of sand grain contact points improves the properties of GMBOND®.

C. **Specialty Sands.** Sand classified as specialty molding aggregates were zircon, olivine, and carbon sand. Figure 5 and 6 shows the bonding strength of the specialty molding aggregates as a function of binder amount. For the zircon sand shown in figure 5, higher tensile strength was obtained with the 0.5% binder level for the first three hours of drying. Higher tensile strength was achieved for the 1.0% binder level for longer drying times. Using amount of binder per aggregate volume for comparison, the 0.5% binder level of zircon can be equated to the 1.0% binder level of silica sand and synthetic mullite. Based on this comparison, the zircon sand exhibited greater tensile strength than the silica and mullite aggregate. However, the grain fineness of the zircon sand was greater. Therefore, zircon sand would display higher tensile strength because of the increased number of sand grain contact points. This observation again supports the hypothesis that the GMBOND® binder behaves better with a finer sand grain distribution.

Olivine sand, as shown in figure 6, exhibited reduced tensile strength as compared to the other molding aggregates previously discussed. Higher tensile strengths were obtained with higher binder levels. It is surmised that the angularity of the olivine sand degrades the sand grain contact point strength. An experiment was conducted with a finer olivine sand having GFN 120. Tensile strength samples out-of-the-box exhibited friability and poor tensile strength, even after drying for 24 hours. Further experiments were suspended with this molding aggregate. As expected, lowering the binder content decreases the bonding strength of GMBOND® as shown in figure 6 for olivine sand. Significant reduction in tensile strength was observed when the GMBOND® content was lowered to 0.5%. Friability and poor tensile strength was observed for these samples.

Very poor tensile strengths were obtained for carbon sand at 1.0% GMBOND® level as shown in figure 6. Because of the poor bonding properties of the carbon sand, further testing at lower binder levels were terminated. Comparing the amount of binder per sand density of carbon sand with the investigated molding aggregates, carbon sand showed to have the lowest amount of binder per volume. This will significantly reduce the bonding properties of GMBOND® for carbon sand. However, based on the proposed reasoning, carbon sand would be expected to have similar tensile properties as silica sand coated with 0.5% GMBOND®. A 70% reduction in bonding properties was observed. During testing, a strong sulfur odor was noticed when water was added to hydrate the GMBOND® binder. It is unclear if the constituents of carbon sand interfere with bonding mechanisms of GMBOND®.

Varying moisture tests were conducted using zircon sand coated with 0.5% GMBOND® binder and olivine sand at 1.0% GMBOND®. Both specialty aggregates exhibited decreasing bonding properties with decreasing water content. A water-to-binder ratio of 2:1, 1.75:1, and 1.5:1 was used for the zircon and olivine sand experiments. For immediate tensile strengths, both olivine and zircon exhibited a reduction of 20% in tensile properties when the water-to-binder ratio was lowered to 1.5:1. At 24 hrs, a 10% reduction in bonding properties were observed when the water-to-binder ratio was lowered to 1.75:1 and a 25% reduction when the water-to-binder ratio was decreased to 1.5:1.

Conclusions.

- Simulated bench life experiments by decreasing the water content indicate that tensile properties degrade with increasing bench life for all molding aggregates investigated. Foundries using the GMBOND® process would be recommended to retard the evaporation of water during transfer and storage until blowing the cores. Experiments would have to be conduct to determine the rate of evaporation and assess the effect of surface sand exposed to the atmosphere on the bonding properties of GMBOND®.
- Experiments investigating the effect of lower recommended binder levels showed a significant decrease in bonding properties. Foundries using the binder would have to periodically re-condition the sand to continuously develop optimal bonding properties. This observation reinforces the research work discussed in Report 1.
- The influence of average grain size has a positive influence on the bonding properties of GMBOND®. Rounded sub-angular aggregates (silica, mullite, and zircon) having a higher GFN improves the tensile strength properties of GMBOND®. Comparing the amount of binder per volume of aggregate indicates a slight relationship between the grain size and contact points. Surprisingly, one would expect lower bonding properties because of the decrease in permeability and increase in surface area as the GFN increases. One possible explanation is the heat transferred to the sand grains to establish flowability of the protein binder is improved with the increase in GFN. Additionally, since a higher GFN represents greater surface area and thinner binder coating thickness, the dehydration process can be accelerated and therefore improve the bonding properties of the GMBOND® binder.

B. Contamination Investigation of Used GMBOND® Binder

Partial and complete decomposition of the GMBOND® binder will occur when exposed to elevated temperatures. Several physical interactions between the completely coated sand grains and the completely decomposed sand grains will influence the properties of GMBOND®, as the used sand is recycled through the sand system. The thermally decomposed material is mixed with fresh, pre-coated sand grains and these sand grains then re-coat the decomposed sand grains. The result is lower total binder coating. It is also unclear if partially decomposed binder affect the bonding mechanisms of GMBOND®.

Problem. Core tensile strength dependency of thermally degraded coated sand.

Objective. To understand the influence of thermally degraded GMBOND® coated sand to gather information how the used binder affect tensile strength.

Measurement system. The tensile strength of the GMBOND® cores was used to determine the maximum tensile stress as a function of time. The standard AFS Procedure 329-87-S was used to determine the tensile properties of the cores. Samples were fractured at the intervals of 5 minutes, 1 hour, 3 hour, and 24 hour from completion of processing cycle. ASF Standard Procedure 321-87-S was used to determine the total organic content of heat-treated GMBOND® coated silica sand.

Experimental Procedure. To assess the recyclability of GMBOND® binder, baseline sand comprising of silica sand (GFN 70) coated with 1.0% GMBOND® was used. The baseline material was divided into four sections. Each of the three sections was placed in a furnace and heated to 400°F, 600°F, and 800°F, respectively. Each section at their respective experimental temperature was maintained at that temperature for four hour. After cooling, the heat-treated sand was added to the GMBOND® coated baseline sand at 5%, 10%, 15%, 25, and 35% additions, respectively. Once the preheated sand was mixed, the sand mixture, without any further coating or conditioning, was mulled as previously described in Section A.

Analysis and Interpretation. Loss-on-Ignition values for each of the heat treatment cycles performed on GMBOND® coated sand is presented in Table 8. The influence of blending degraded sand to pre-coated 1% GMBOND® sand is presented in Figure 8 to 10. For all degraded sand addition experiments, the tensile strength properties decrease as the amount of thermally degraded sand is added increases. The figures also illustrate that as the temperature of degraded sand increases, the tensile strength properties decrease as the addition level remains constant. Another experiment was conducted to assess re-coating capability properties of sand thermally degraded. The information is presented in Figure 11. Slight loss in tensile properties were observed for the 400°F and 600°F heated treated sand but noticeably higher tensile properties were observed for the re-coated 800°F sand. An experiment was conducted with the 400oF heat-treated sand in the heat-treated condition. Water was added at a 2% addition. Slight bonding was observed but tensile strength bar could not be successfully removed from the core box without crumbling.

Table B-1. Loss-on-Ignition of GMBOND® coated sand.

Heat Treatment (One hour treatment time)	Loss-on-Ignition (1400°F @ I hour)
Untreated	1.17%
400°F	0.77%
600°F	0.38%
800°F	0.00%

Summary. Experiments showed progressive degradation of tensile strength properties as the amount of thermally exposed sand increases. Buildup of 35% thermally degraded sand within a sand system would meet production requirements of GMBOND® cores. Re-coating of the sand would be recommended when a noticeable decrease in tensile strength is observed, indicating the percentage of thermally decomposed sand exceeds the percentage of thermally unexposed GMBOND® coated sand. Experiments performed on re-coating heat treated sand to the original 1% binder level indicate no significant loss of properties. This observation indicates that only mechanical reclamation of GMBOND® is required and thermal reclamation would have no added value benefit to production requirements.

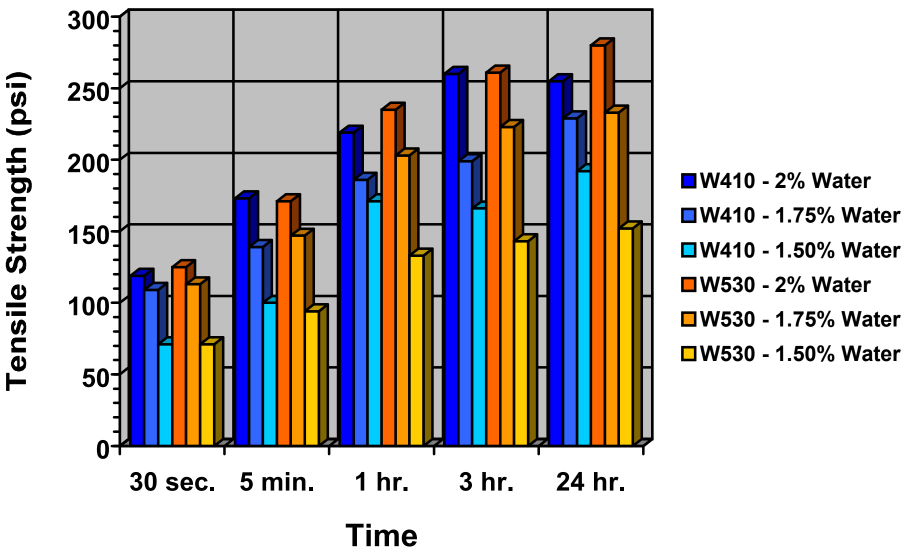

Figure 1. Results of tensile strength experiments using silica sand coated with 1% GMBOND® binder. A water-to-binder ratio of 2:1, 1.75:1, and 1.5:1 was used for W410 and W530 experiments.

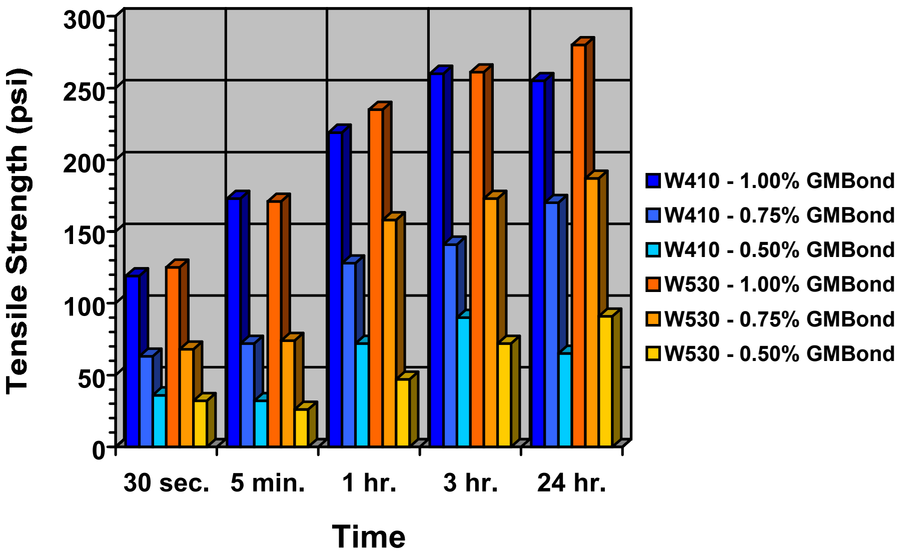

Figure 2. Results of tensile strength experiments using silica sand coated with 1%, 0.75%, and 0.5% GMBOND® binder. A water-to-binder ratio of 2:1 was used for W410 and W530 experiments.

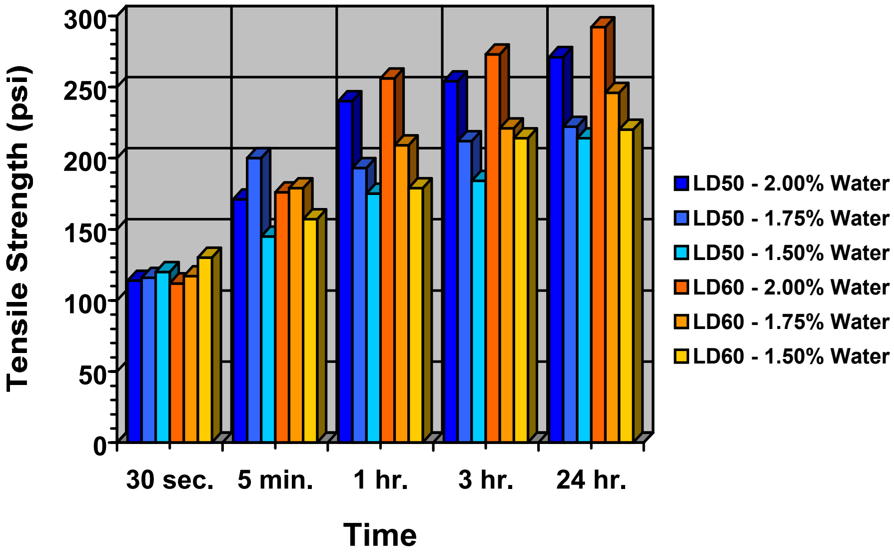

Figure 3. Results of tensile strength experiments using synthetic ceramic mullite aggregate coated with 1.0% GMBOND® binder. A water-to-binder ratio of 2:1, 1.75:1, and 1.5:1 was used for LD50 and LD60 experiments.

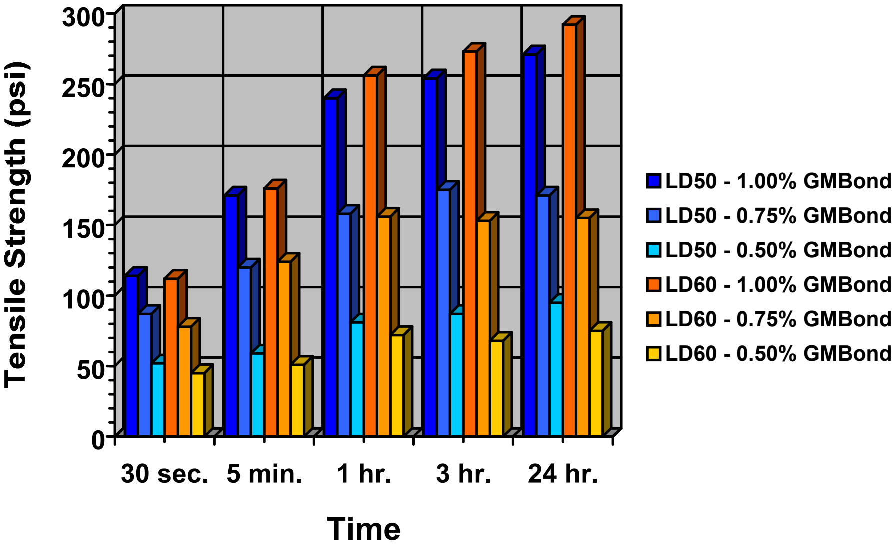

Figure 4. Results of tensile strength experiments using synthetic ceramic mullite aggregate coated with 1.0%, 0.75%. 0.5% GMBOND® binder. A water-to-binder ratio of 2:1 used for LD50 and LD60 experiments.

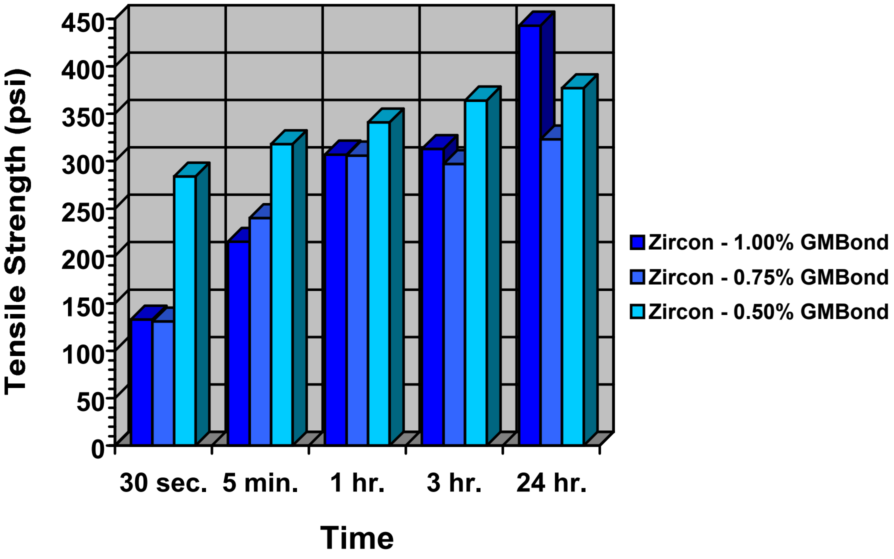

Figure 5. Results of tensile strength experiments using zircon sand coated with 1.0%, 0.75%. 0.5% GMBOND® binder. A water-to-binder ratio of 2:1 used for zircon sand experiments.

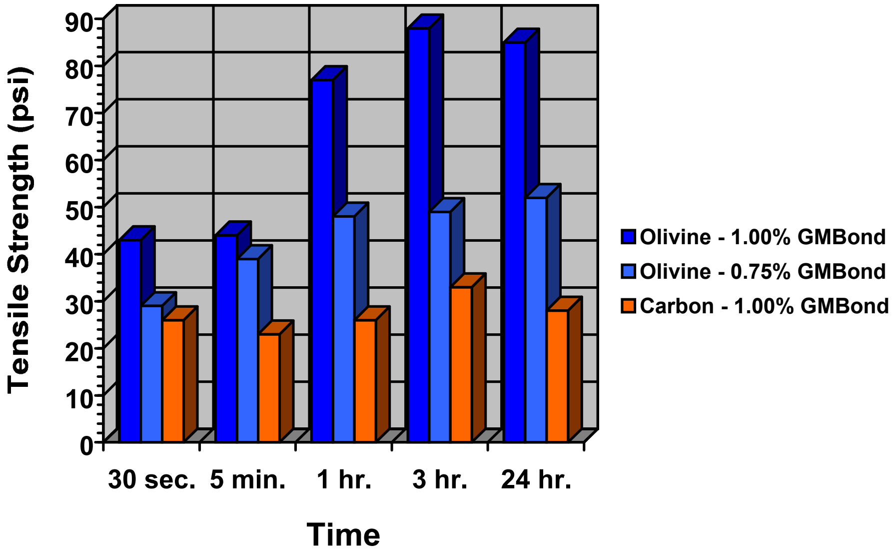

Figure 6. Results of tensile strength experiments using olivine sand coated with 1%, 0.75% GMBOND® binder and carbon sand coated with 1.0% GMBOND® binder. A water-to-binder ratio of 2:1 used for the olivine and carbon sand experiments.

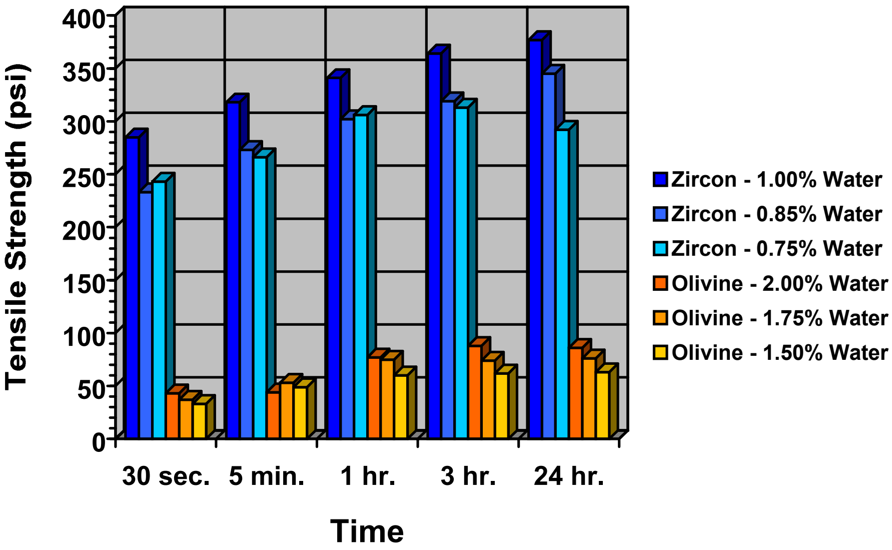

Figure 7. Results of tensile strength experiments using zircon sand coated with 0.5% GMBOND® binder and olivine sand coated with 1.0% GMBOND® binder. A water-to-binder ratio of 2:1, 1.75:1, and 1.5:1 was used for zircon and olivine sand experiments.

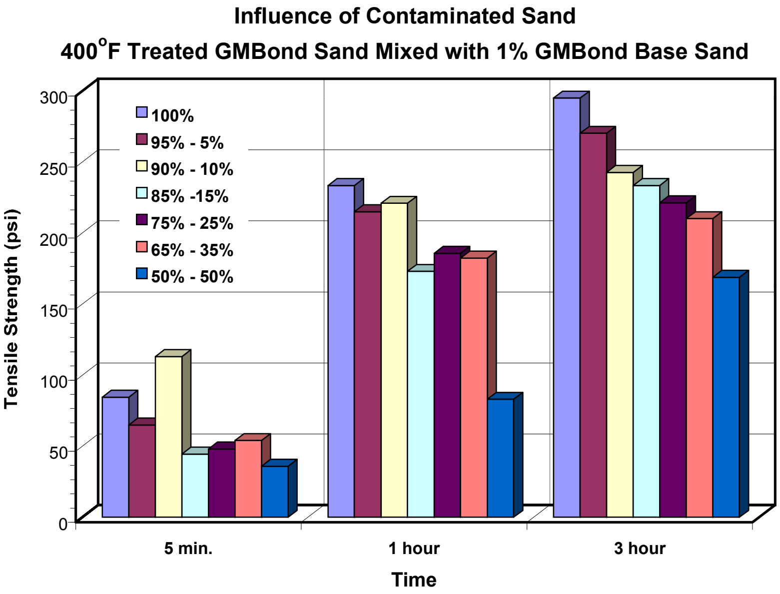

Figure 8. Tensile strength properties of GMBOND® sand blended with 400°F thermally degraded GMBOND® coated sand.

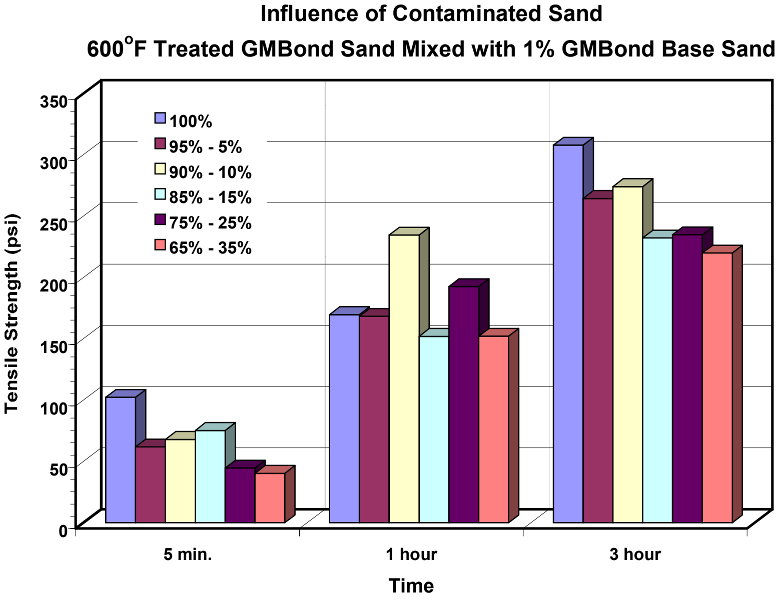

Figure 9. Tensile strength properties of GMBOND® sand blended with 600°F thermally degraded GMBOND® coated sand.

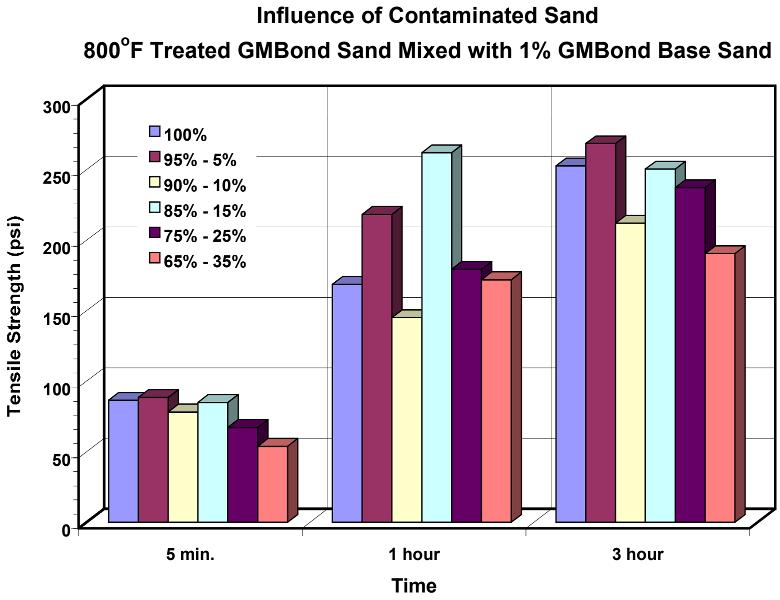

Figure 10. Tensile strength properties of GMBOND® sand blended with 800°F thermally degraded GMBOND® coated sand.

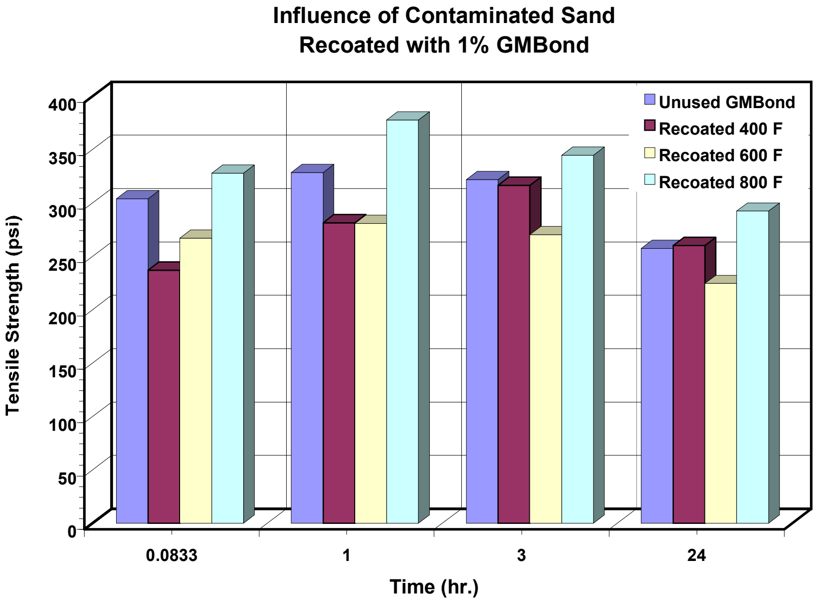

Figure 11. The effect of recoating GMBOND® sand exposed to elevated temperatures.