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Investigating the production of cores by using reclaimed foundry green sand

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INVESTIGATING THE PRODUCTION OF CORES BY USING RECLAIMED FOUNDRY GREEN SAND

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

Kristopher Lee Boss

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ABSTRACT

Increasing environmental regulations, transportation cost, delivery interruptions leading to production concerns, disposal cost, and demand from other industries have influenced the way foundry's view used sand. The purpose of this research was to determine a beneficial reuse of overflow-green sand that would normally be disposed. The reclamation process used is a combination of mechanical and wet reclamation. The focus was on the production of foundry cold box cores and if using this reclamation process could create a core with a similar quality performance compared to new sand. Research in reclamation could pave the way for a closed loop sand system, where only small additions are needed to maintain a similar quality sand system as regularly purchasing new sand.

The following methods were used to determine the sand quality: scanning electron microscope examination, loss of ignition, screen distribution, transverse tensile, tensile properties, core density, sand expansion dilatometry, surface area and coefficient of angularity, and production casting trials. Compared to new sand, the tensile strength increased with the reclaimed sand samples when a similar sand sized grain distribution and binder amount was used. Additional benefits include increased core density, better flowability during core production and a reduction of veining type defects. The proprietary reclamation process used indicates overflow green sand can be reclaimed to produce cold box cores that are equal or improved to new sand.

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Entitled: Investigating the Production of Cores by Using Reclaimed Foundry Green Sand

has been approved as meeting the thesis requirement for the

Degree of Master of Science

Date	Dr. Scott Giese, Chair, Thesis Committee
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Date	Dr. Jennifer Waldron, Dean, Graduate College

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CHAPTER 1

INTRODUCTION

Statement of the Problem and Purpose of the Study

The purpose of this research is to determine if used foundry green sand can be recycled through a reclamation process for producing cold box cores that are equal or better quality than using new sand. The sand of interest in this research will be defined as "overflow" green sand. This is the sand typically disposed at a landfill. The breakdown of cores during the casting process continually adds new sand to the green sand system eventually leading to an excessive amount needing to be removed. The overflow sand is comprised of used green sand, new sand, solid pieces of non-broken-down cores, small amounts of shell sand and other trace amounts of materials (such as iron from pouring). The sand will be tested in various ways and compared to new sand to understand the differences in quality for the casting process.

Increasing environmental regulations, transportation cost, transportation delays leading to production concerns, disposal cost, and demand from other industries have influenced the way foundry's view used sand. In the past, the incentive for a foundry to use a reclamation process had a small financial benefit because the cost of new sand is comparable to the cost of reclaiming. Because of the concerns listed above, especially from an environmental standpoint, is causing the foundry industry to reevaluate sand reclamation using thermal, mechanical, and or wet-reclamation processes.

Significance of the Study

Green sand is a mixture of silica sand, clay, water and some additional additives. It is used within the foundry industry to create a green sand mold that is filled with liquid metal to create a casting. The purpose of this research is to determine the beneficial reuse of overflow green sand that would normally be disposed. This material could be recycled as a consumable product for the foundry which can have positive financial, quality and environmental impacts.

Research in reclamation could pave the way for a closed loop sand system, where only small additions are needed to maintain a similar quality sand system as regularly purchasing new sand. Potential other benefits include a reduction in the amount of binder used for mold and core production, minimizing sand storage, and sand transportation related cost and delays that could disrupt production (weather related incident as an example).

Hypothesis

H_o= Determine if overflow green sand can be reclaimed to produce cold box cores that are equal or improved to new sand in the following ways: mechanical and physical properties, veining and penetration defects, and potentially other casting related defects (such as gas).

The reclamation process used in this research is considered proprietary. This process is a combination of wet and mechanical reclamation. Only the general process is described in this research.

Statement of Procedure

The procedure for this study will be:

1. Determine the mechanical, physical and chemical characteristics of the reclaimed sand by performing the following lab test: screen distribution, 3-point transverse test, tensile test, core sample weight, dilatometry, LOI, ADV and PH.
2. Perform a casting trial to compare cores made from new and reclaimed sand concerning casting defects, primarily on metal penetration and veining defects.
3. Collection and review of the lab and production data to validate or reject the hypothesis.

Limitations and Assumptions

1. This study is being conducted at a foundry which produces only gray and ductile iron using silica sand, a bentonite mixture of western and southern clay, seacoal and cereal.
2. Only sand reclaimed from this foundry was used for the research.
3. A similar GFN silica sand is used for core and green sand production. John Deere Foundry used eight screens while the UNI MCC used ten to determine the GFN.
4. The details of the reclamation process are proprietary information and is not shared in this study. Patent numbers 6554049, 6834706.
5. The reclaimed sand was only used to produce phenolic urethane cold box cores.

6. Testing was conducted at a 3rd party lab (UNI Metal Casting Center), the John Deere Foundry, and the Scanning Electron Microscope lab at John Deere Product Engineering Center.

Definitions of Terms

Bag house – An air pollution control device and dust collector that removes particulates and gas released from mold pouring out of the air.

Bench life – The amount of time the coated sand can be stored without a degradation of the physical properties of the binder system

GFN – Grain-fineness number is a system developed by the American Foundry Society (AFS) for expressing the average grain size of a given sand.

LOI – Loss on ignition consists of heating a sample of material at a specified temperature, allowing volatile substances to escape, until the mass change is stable.

Shake out – The operation of removing the casting from the mold (green sand).

Shelf life – The amount of time cured cores can be stored before any degradation occurs.

Slag – A nonmetallic covering on molten metal as the result of the combining of impurities contained in the charge materials, silica and clay eroded from the refractory lining. May also originate from metal reactions occurring in the ladle and or during pouring of the casting.

Ramability – Indication of a molding sands workability when pressed against a pattern.

CHAPTER 2

LITERATURE REVIEW

The foundry industry heavily depends on the use of sand to make a useable casting that can be sold to customers worldwide. A casting is made by pouring molten metal into a mold cavity, formed by using sand. Foundry molding sand can withstand the extreme temperatures observed during the pouring and solidification of the liquid metal. The abrasive resistance of sand makes it ideal to withstand the highly physical process of mulling, high pressure compaction, and shake out.

Foundry sands are unique to the foundry, depending on the process and application. The size of the sand is one important aspect and is separated by using a screening process until the desired size or distribution is achieved. Different types of sand have different densities, compositions, and shapes that can all affect the casting process and quality. The most common ways to bond these sand grains to make a usable mold is by using chemicals (chemically bonded sand) or with clay (green sand). The reason for the term “green sand” is due to the use of water. The water will activate the clay causing the silica grains to bond together.

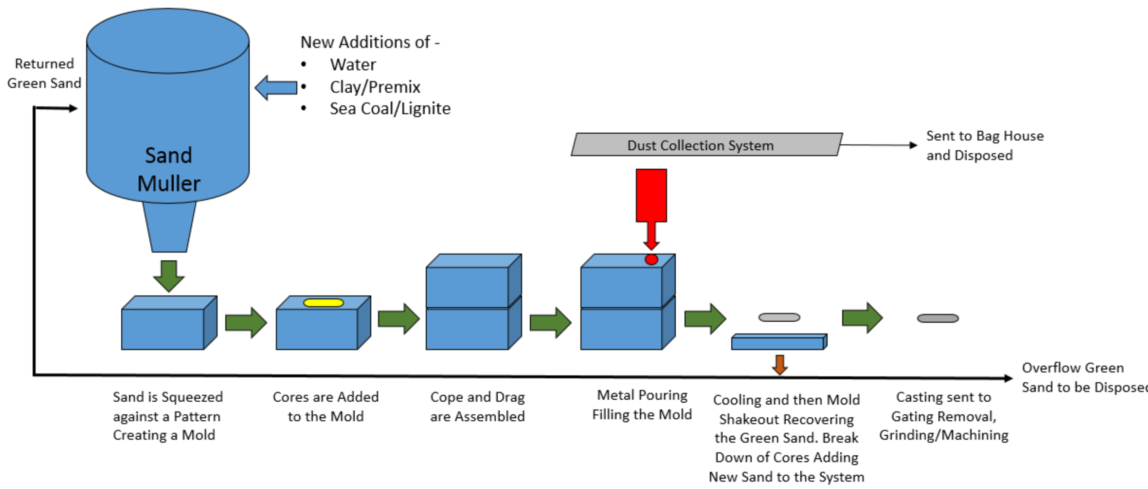


Figure 1 *A Typical Molding and Pouring Process. After the shakeout process, sand is either cooled and returned to the muller or disposed of as Overflow Green Sand. (Fox, 2009)*

Figure 1 demonstrates a typical horizontal molding and pouring process for creating a casting from green sand. Depending on the foundry, new additions of silica sand could be added directly to the muller, or in this case relies on the breakdown of cores as a source of new sand additions. Typically, five to ten percent of green sand is removed from the sand system daily to account for excessive sand from the new sand additions. This excessive sand is identified as overflow green sand, the primary focus of this reclamation research. The overflow green sand has a similar grain size (GFN) as the green sand returned to the muller to be reused for production. The bag house is another source of silica sand but is typically comprised of undesirable fine sand particles. These particles accumulate from the molding process when the sand breaks into smaller pieces. The bag house also contains clay, which current literature reviews indicate can be reintroduced to the green sand system as a hydrated clay slurry (Torielli, 2014).

Green Sand and Additives

Green sand's most important characteristic is its ability to form an adhesive coating around particles of sand when mixing the sand with clay and water. This mixture can form under compaction to create a mold for the molten metal to be poured in. The extreme temperatures of the iron cause the green sand to burn the clay and evaporate the water, resulting in the easy removal of the casting during the "shake-out" process. The type and amount of clay used in green sand can depend on several factors such as: 1) pouring temperature of the alloy, 2) size and section thickness of the casting 3) shakeout characteristics of the mold (American Foundry Society, 2003). Typically, a pre-blend of different clays and additives are added to the molding sand to gain the optimal properties for molding depending on the factors described above.

Western bentonite (or sodium bentonite) is primarily mined in the western part of the USA such as South Dakota, Montana and Wyoming. This clay provides a very high hot strength and is used mainly in ferrous alloy castings where the metal temperatures and pressures require a higher hot strength in the mold. This clay increases the sand durability and toughness, and molds made with Western bentonite develop sharp, strong mold edges and corners. Its high durability results in replacing less clay during recycling or reuse for molding (Zabetti, 2003). Western bentonite requires longer mixing or mulling time to fully activate the clay, compared to southern bentonites. This clay will give the molding sand a lower green compression strength.

Southern bentonite (or calcium bentonite) is primarily mined in the southern part of the USA in Alabama and Mississippi. Southern bentonite clay falls in the similar mineral structure as western bentonite, but because of the substitution of a calcium ion for the sodium ion in western bentonite, it is classified as a non-swelling bentonite and provides much lower hot strengths in a mold. The lower hot strengths cause the castings to shake out with less energy compared to western bentonite. Southern bentonite also increases the green compression strength and improves the ability for the sand to form around the pattern, sometimes referred to as “rammability”. The squeeze and blow pressures can be reduced because of this increased rammability increasing the density of the mold.

An additional additive commonly used in cast iron foundries is a carbonaceous material, known as seacoal. The main purpose of seacoal in green sand is to improve the surface quality of the casting. There are a couple theories how seacoal can make this improvement; one is when the metal burns the sealcoal (during pouring), it depletes the amount of oxygen in the mold. A second theory, the gasses generated by the burning seacoal recondenses when they contact the sand grains and coat them with lustrous carbon, providing peel characteristics at the mold-metal interface during shakeout. Another beneficial aspect of seacoal is the expansion characteristics that fills the voids between the sand grains which enhances the casting finish (American Foundry Society, 2003).

Foundry Cores

Cores are used to create a void in the mold so molten metal can flow around the cored area during filling. Cores are created similarly to the casting process, using a mold cavity (corebox) to blow chemically treated sand into the empty cavity. Depending on the binder system, a type of catalyst is used to accelerate the chemical reaction which bonds the sand particles together. There are three different types of chemical binder systems and are classified as: heat activated, cold box and no-bake (or air-set). Each of the binder systems are affected differently by alkaline or acidic impurities, moisture content and overall sand type. It is important to understand how these impurities can impact the performance of the binder (American Foundry Society, 2003). There are numerous different binder systems for creating cores, but the purpose of this research will be focused on cold box phenolic urethane and shell cores. These are the two types of cores used at the John Deere Foundry that can be part of the overflow green sand system.

Cold box binder systems are the most commonly used systems in today's industry because of their ability to produce a large quantity of cores and at a high rate of speed. The phenolic urethane system is composed of two resin parts. Part 1 is a phenolic resin dissolved in an organic solvent, and part 2 is an isocyanate component dissolved in a similar solvent. These two binders are mixed with new foundry sand until the sand grains are uniformly coated in the two parts. The chemically treated sand is blown into a core box, filling the empty void with treated sand. Depending on a couple of factors, the coated sand must be used within a specific amount of time before degrading the physical properties of the core. This is referred as the "bench life" of the chemically treated sand.

The use of a vaporized gas catalyst (DMEA in this case) is blown through the treated sand curing the binder around the sand grains causing them to bond together. The partially cured and hardened cores can then be removed from the core box. The core is only 70-80% cured until the remaining solvent evaporates from the binder (American Foundry Society, 2003).

Shell or heat-activated cores work by coating clean, quality silica sand with a flake phenolic novolak resin when the sand is heated. The elevated temperature melts the resin coating the sand. This hot sand mixture is then quenched and mulled until the sand breaks into smaller, useable particles. The sand will go through another screening process to remove any undesirable chunks of sand and resin which cannot be broken down from mulling. The sand is now pretreated with resin and can be used to make a core using a heated core box. The pretreated sand is blown into the heated core box and depending on section size and the geometry of the core, the sand will dwell at a specific amount of time until the resin melts and creates the bond between sand grains. Only the sand that is exposed to enough heat to activate the resin will be cured. The core box will then be rotated so any uncured sand can be removed from the core, making it hollow (depending on the core geometry, the removal of uncured sand may not be possible). The shell of the core is removed from the core box and used for production after the core has cooled. The shell process offers several advantages, such as an indefinite bench and shelf life, hollow cores make the shakeout process easier and shell cores produce smooth cored surface finish on the casting (American Foundry Society, 2003).

Environmental Impacts and Disposal of Used Green Sand

Green sand is repeatedly processed and reused in foundry until it becomes unusable in some manner that requires disposal. During this process, the sand is exposed to temperature extremes and mechanical forces which deteriorate the sand. The sand can break into smaller pieces which become undesirable for the foundry process and disposal is needed. The smaller pieces would increase the GFN of the sand system causing more sand to be retained on the higher screens. Another area which also requires disposal is overflow green sand. This term of “overflow” green sand is referred to as excessive sand within the sand system which has been traditionally transported to a landfill without modification. This material can contain molding sand, knocked out core sand, core butts and other materials (LaFay, 2015). Typically, 90% of used green sand goes to a landfill as non-hazardous waste while only 10% is beneficially reused (U. S. Enviromental Protection Agency (EPA), 2002). A single foundry can generate numerous wastes, including spent molding and core sands, unused and broken cores, core sand waste, core room sweepings, cupola slag, scrubber sludge, baghouse dust and shot blast fines (U.S. Enviromental Protection Agency (EPA), 2014).

According from a study from the EPA, USDA and Ohio State University (U.S. Enviromental Protection Agency (EPA), 2014), roughly 2.6 million tons of spent foundry sand is beneficially used outside of the foundries, of which 14% is used in soil-related application. Foundry sand has been used as a substitute for virgin sand in certain markets such as: highway and construction use, aggregate substitutes and manufactured soils. Used foundry sands are potentially useful in manufactured soils because of their uniformity, consistency and dark color of the green sand. Numerous studies have concluded that used sand from brass foundries are generally not suitable for beneficial reuse due to high levels of metal contaminants (Owens, 2008)

Reclamation

The primary consideration that has guided the course of sand reclamation development has been the technical success of the particular process in terms of the quality of the reclaim sand; today the important considerations are (a) the cost of energy employed in the process, (b) the amount of land that is required to support the processing equipment, (c) governmental regulations of waste disposal, and (d) density or chemical variability of the reclaim sand preventing sand bonding for core making (Owens, 2008).

Ideally, a sand reclamation system would process sand at a maximum yield and return the sand in such condition that it would be suitable for re-use with any binder system. The sand would then be used to produce castings with no defects, while maintaining a low operational cost. However, this is difficult and expensive to achieve, and in practice compromises are made. Generally, the purer and cleaner the reclaimed sand, the higher is its utilization in mixes and lowers the requirement for new sand additions (Svoboda, 1990). For the purpose of this research, the three most common methods of reclamation will be investigated.

Thermal

Thermal reclamation is a process using sand containing resins that are heated to the temperature enabling total or partial burning of organic binder and carbonaceous material such as seacoal (Danko, 2010). This process can be expensive as it requires a large amount of energy to heat the sand to 500-800°C, followed by a cooling process to return the sand to room temperature. This reclamation process is limited to organic binders, as there is an inability to burn-off or remove inorganic binders such as clay. Some of the different types of machinery used for thermal reclamation are rotary kilns, fluidized beds and shaft furnaces. The advantage of thermally reclaimed sand is a stabilization of its volume metric expansion at an increased temperature related to the quartz allotropic transformation during previous warming of sand adjusted to casting. This stability enables applying the reclaimed sand in practically every molding and core sand technology. (Danko, 2010)

Mechanical

Dry mechanical reclamation systems liberate sand grains from the coatings of binding material(s) completed by a combination of the following operations: rubbing, abrasion, and crushing of binding material coatings from the surface of the sand (Danko, 2010). This highly physical process causes the sand to be crushed into smaller pieces which may not be ideal for molding. Excessive fine particles of sand can lead to mold permeability issues that lead to gas related casting defects. These fine particles of sand need to be removed, typically by relying on the use of a dust collection system (bag house). However, compared to thermal reclamation, mechanical reclamation is generally inefficient because it cannot remove the organic binders from the individual sand grains, limiting its application (Owens, 2008). The existing binder remaining on the sand can lead to excessive gas related issues if the sand is reused for core production.

Wet Reclamation

Wet reclamation is the most efficient reclamation method for used sands with binding agents and for sand containing water-soluble binders (silica sands, sands with water-glass hardened by CO2) (Danko, 2010). This process can use an abundant amount of water and may be subject to an intense wet-scrubbing action which can be obtained by pumping or mechanically agitating a properly proportioned mixture of used sand in water. This ultrasonic scrubbing action removes the clay and phenolic binder coating the sand grains in water. The clay is then carried off by the water.

Ultrasonic cleaning has been attributed to three forces; chemical reactions between the soluble impurities and the cleaning agents in water, dissolution of the impurities from the surfaces into solution, and the ultrasonic cavitation removing the insoluble impurities from the surface (Niemczewski, 2007). Cavitation is generated by applying intense sound waves in a liquid. These sound waves create alternating regions of compression and expansion that can form bubbles 100µm in diameter. The bubbles implode violently in less than a microsecond, heating their contents to 5,500˚C. The compression cycles exert a positive pressure on the liquid, pushing the molecules together; expansion cycles exert a negative pressure pulling the molecules away from one another (Suslick, 1989).

Another application using ultrasonic technology is an advanced oxidation process (AO). The AO system recently has been enhanced to include hydroacoustics – cavitation and virtual cyclone. AO can be applied to overflow green sand and baghouse dust in a manner that restores the binding activity of the clay and sand (Torielli, 2014). Once the clay is removed using this system it can be reused in the green sand system as a slurry. This is a proprietary system manufactured by an American company.

The U.S. based company developed an advanced oxidation system that applies ozone, hydrogen peroxide, and sonication in a water-slurry, as seen in Figure 2. This system reprocesses bag house waste dust, via a slurry known as “black water.” The baghouse dust slurry is treated with advanced oxidation; and replaces the conventional water source for the green sand molds. Previously published papers indicate that the process requires 27-60% less clay and coal and 20-37% less silica sand and produces 19-70% lower VOC air pollution during pouring, cooling, and shakeout (Torielli, 2014).

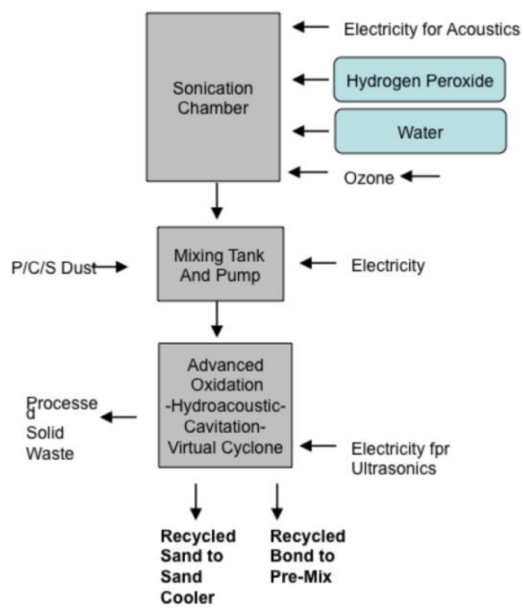


Figure 2 *Advanced oxidation – hydroacoustic cavitation for reclaiming green sand and baghouse dust (Torielli, 2014).*

Prior Lab Results

Prior to the research conducted in this study, testing was performed at the University of Northern Iowa's Metal Casting Center (UNI MCC). Several tons of overflow green sand from the John Deere Foundry were reclaimed using this proprietary process and sent to the UNI MCC for testing. After reviewing the initial results from the UNI MCC report, the remaining sand was sent to the John Deere Foundry for an internal analysis. The researcher was actively involved with the lab testing at both labs and management of the reclamation project.

It is important to note the same reclaimed sand was used at each lab. Some of the same sand test were conducted at both labs. Additional sand tests were conducted at each lab depending on the equipment capabilities. As an example, the scanning electron microscopy work was conducted at the John Deere lab while pH, ADV and dilatometry testing was performed at the UNI MCC. Casting trial were performed at both labs, however the method used differed between step-cone castings and John Deere Foundry production castings for tractors. The initial results collected at the UNI MCC will be referenced and compared to results shared in Chapter 4 for the internal analysis.

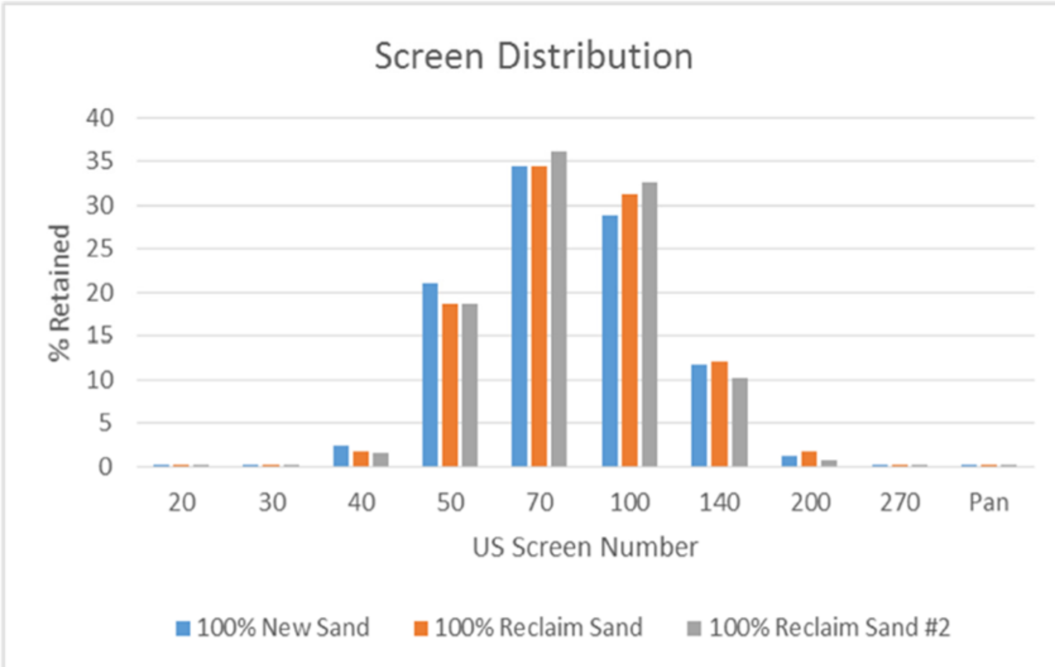


Figure 3 *The AFS screen distribution of new sand and reclaimed sand. Reclaim sample tested twice. Results from UNI MCC (Ravi, 2014)*

Dog Bone Tensile Results

The tensile strength was determined using a cold-box core box in the shape of a "dog bone." The reclaimed sand had higher tensile strengths compared to new sand. Blends of reclaimed sand and new sand at 50/50 and an 80/20 ratio were also examined. These results follow a similar trend, the higher percentage of reclaimed sand resulted in higher tensile strengths.

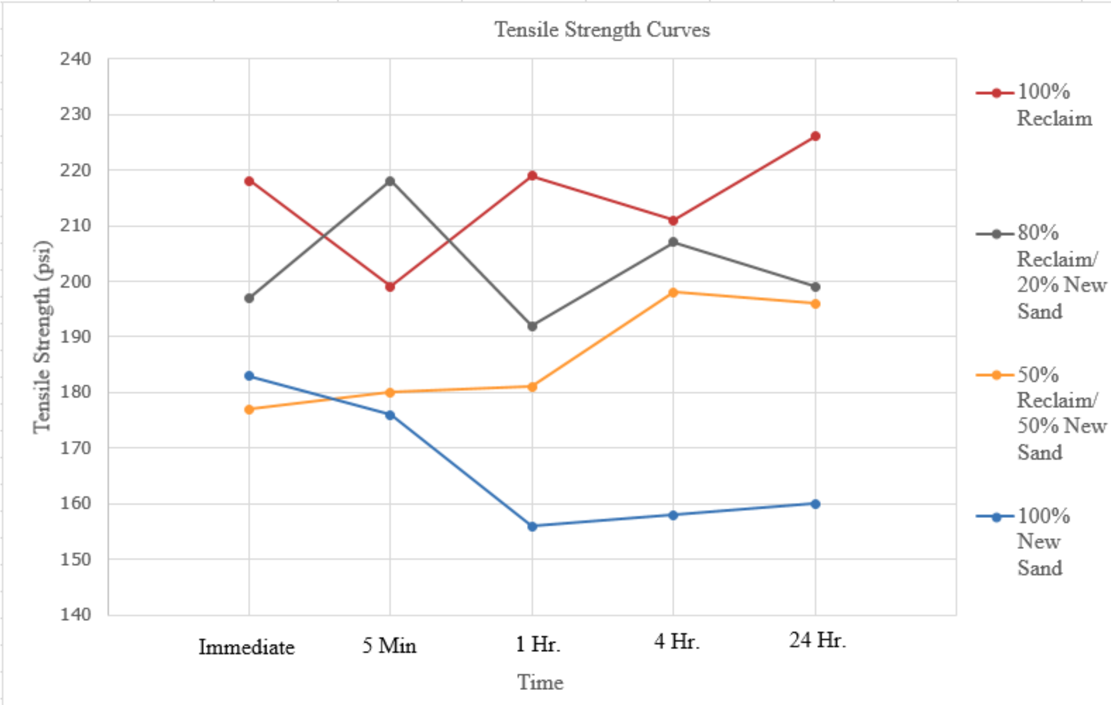


Figure 4 *UNI MCC testing results for dog bone tensile testing (Ravi, 2014)*

Surface Area and Coeifficient of Angularity

Shown in Table 1, the surface area and coefficient of angularity was determined at the UNI Metal Casting Center. The surface area with the new sand was 170.536cm^2/g and decreased to 158.183 cm^2/g with reclaimed sand. The slight decrease in surface area is also reflected in the coefficient of angularity, in which the reclaimed sand is more 'round' compared to the new sand. More angular and lower sphericity sands may require additional binder to achieve similar properties to sands which are well rounded with high sphericity due to the difference in surface area.

Table 1 UNI MCC results for Surface Area and Coefficient of Angularity (Ravi, 2014)

Sample ID	Surface Area (cm^2/g)	Coefficient of Angularity
100% New Sand	170.536	1.077
100% Reclaim	158.183	1.043

Sand pH, ADV and LOI

The reclaimed sand is more acidic as seen in Table 2, approximately a 1pH difference. There is a large difference with the ADV (acid demand value) of 0.663 with new sand and 6.317 with reclaimed. The higher ADV result indicates more acid would be required to neutralize the sand to a pH of 7.0. The ADV can also be an indicator measuring any impurities in the sand. The ADV and pH can be critical to an acidic type binder system (hotbox, silicate CO2, SO2 furan, SO2 acrylic epoxy) where an alkaline catalyst is used to cure the core. In a phenolic urethane cold box binder system, which is how the cores are produced; a higher ADV can minimize the bench life of the sand.

The raw sand with no binder had an LOI% of 0.065% with new sand, and 0.515% with the reclaimed sand. The results indicate the reclamation process does leave some residual material on the grains of sand, approximately 0.5% .

Table 2 UNI MCC results for pH, Acid Demand Value and Loss of Ignition. (Ravi, 2014)

Sample ID	pH	ADV	LOI (%)
100% New Sand	7.003	0.663	0.065
100% Reclaim	8.130	6.317	0.515

<u>Sand Expansion Dilatometer Results</u>

As seen in Figure 5, there is a noticeable difference with the Alpha-Beta phase transition around 1058˚F. This peak expansion and the subsequent contraction of silica sand is responsible for causing veining defects in castings. Hence, the reduced peak expansion may decrease the veining defects seen in castings (LaFay, 2015). The peak expansion during this phase was approximately 0.9% for new sand and 0.6% with reclaimed. The blended samples showed a similar trend, the addition of reclaimed sand reduced the linear expansion during this phase transformation.

After the Alpha-Beta phase transformation there is a contraction leading to another much larger expansion, the cristobalite phase transition. The contraction of the reclaimed sand is less severe as compared to the new sand. The reclaimed sands peak expansion was 0.6% contracting to 0.5% and the new sand was 0.9% to about 0.4%. This is approximately a 20% difference with the reclaimed sand and 60% with new sand. This less severe contraction of the reclaimed sand lead to less veining type defects as seen in Figure 6 and Figure 7 from the step cone casting trials. The onset of the cristobalite phase transformation occurred at an earlier temperature with the reclaimed sand. New sand has not been exposed to excessive temperatures from the casting process. The reclaimed sand experienced these temperature extremes causing them to suppress the linear expansion during subsequent temperature extremes from pouring.

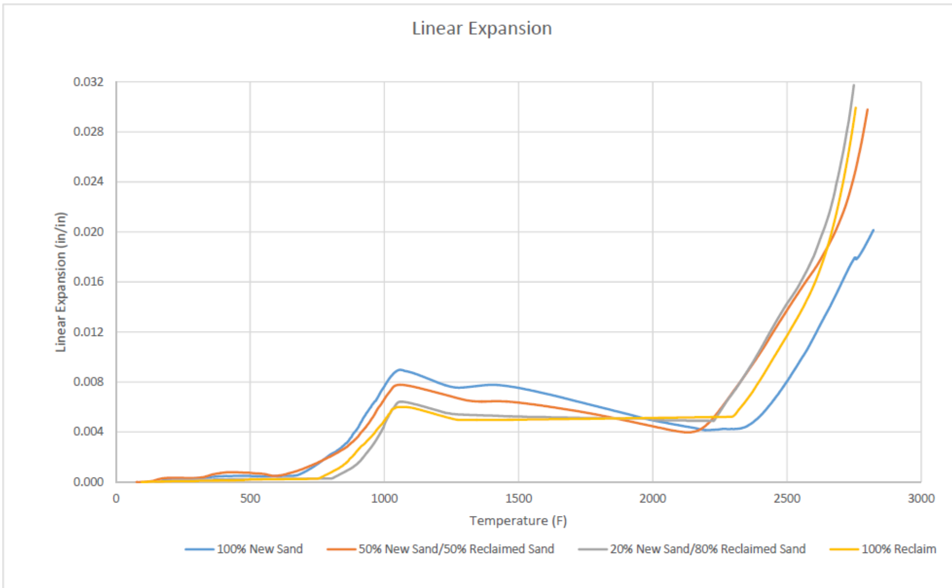


Figure 5 *Linear Expansions of New, Reclaimed and Blended sands (Ravi, 2014).*

Table 3 *Summarized Expansion Characteristics from Figure 5*

Sample ID	**Peak Expansion at Alpha-Beta phase Transition ~1058°F (in/in)**	**Sinter Temperature (°F)**
100% New Sand	0.0090	2313.4
50% Reclaim, 50% New Sand	0.0078	2143.7
80% Reclaim, 20% New Sand	0.0064	2226.6
100% Reclaim	0.0060	2294.3

Step-cone Casting Trials

Step-cone molds and cores were produced at the UNI MCC. Evaluating step cone castings is considered the optimal choice to evaluate the overall casting performance. (Tordoff, 1980). The new sand had a higher amount of veining compared to the reclaimed sand. However, there was a slight increase in penetration defects with the reclaimed sand. The summarize results are shown in Table 4.

The decrease in veining defects with the reclaimed sand can be associated with the linear expansion results seen in Figure 5. The reclaimed sand has a smaller contraction after Alpha-Beta transition. Previous research has shown the cause of veining defects is not the expansion of the sand but the contraction after the Alpha/Beta phase transformation (Thiel, 2007).

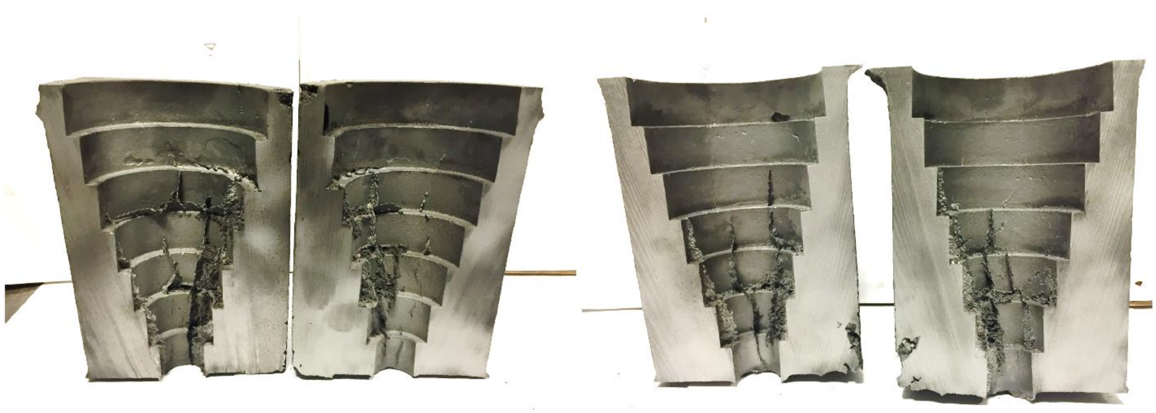


Figure 6 100% New sand Step Cones (Ravi, 2014)

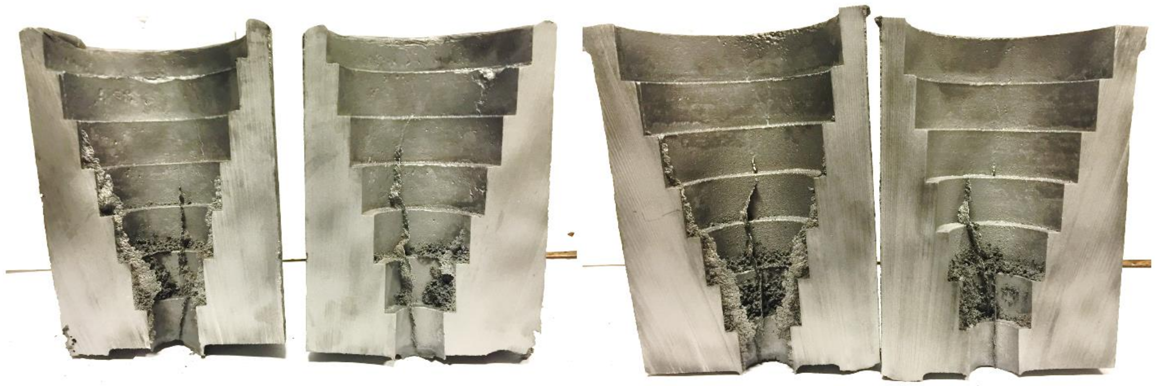


Figure 7 100% Reclaimed sand Step Cones (Ravi, 2014)

Table 4 UNI MCC Step-cone Veining and Penetration Results (Ravi, 2014)

Sample	Veining Index	Penetration Index
New Sand	47	7
Reclaimed Sand	19	15

CHAPTER 3

METHODOLOGY

The primary purpose of this study is to determine if overflow foundry green sand can be reclaimed to produce cores that have a similar quality performance as cores made from new sand. During the initial study, side-by-side comparisons are conducted by performing lab trials with new and reclaimed sand. Lab testing was conducted at the John Deere Foundry sand lab and at the UNI Metal Casting Center (MCC).

Microscope Analyses

The scanning electron microscope/energy dispersive spectroscopy (SEM/EDAX) was used to determine the chemical characteristics before and after the reclamation process. An EDAX ‘Mapping’ method was used to identify the type and amount (weight percentage) of any residual elements from the binder systems. This analysis indicates how well the reclamation process ‘cleaned’ the sand to remove either organic or in-organic additives.

Stereomicroscope images of new, overflow green sand and reclaimed sand were captured at 25X magnification. Characteristics of the sand regarding color and a surface appearance were documented.

Mechanical Properties

Transverse tensile samples at the John Deere Foundry were made at 1.2% binder based on sand weight (BOS), using a 50:50 ratio of Part I: Part II phenolic urethane resin. The sand was split using a 50/50 splitter until achieving a batch weight of 3000 grams.

The sand was mixed for 60 seconds after adding the Part I resin, followed by an additional 60 seconds when adding the Part II resin. The mixture was taken to the cold box core machine which can make three samples per cycle as seen in Figure 8. Gassing and purging pressures of 20psi and 40psi were respectively used. The cores were gassed for 0.5 seconds and purged for 7 seconds. The testing conducted at John Deere started at ten minutes due to the distance between the sand lab and core box machine where the samples were produced. Samples were tested at ten minutes, thirty minutes and sixty minute break times. The round transverse samples were tested on a 3-point fixture seen in Figure 9.

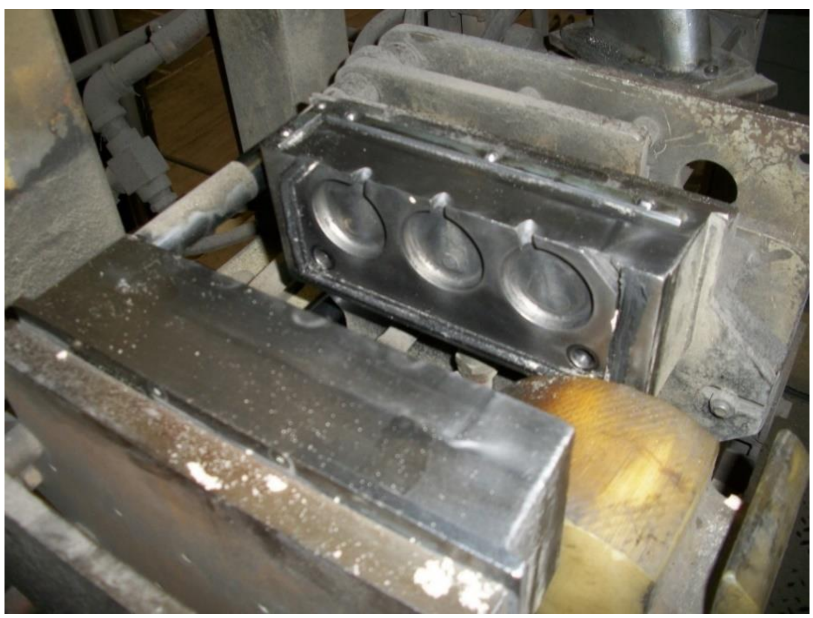


Figure 8 Transverse Tensile Cold Box Core Mold, John Deere Foundry

Figure 9 *The transverse tensile testing machine, John Deere Sand Lab.*

Tensile strength (dog bone shape) testing performed at the UNI MCC had a binder content of 1.6% BOS, and a Part I: Part II ratio of 50:50 using a phenolic urethane binder. The sand was split using a 16-way sand splitter to achieve a representative sand grain distribution. A split batch of sand was added to a mixer where the Part I resin mixed for 60 seconds, followed by adding the Part II resin that mixed for an additional 60 seconds. The final mixture was used to make dog bone tensile samples using a Redford core box machine (Figure 10). The gassing and purging pressure of 20 psi and 40 psi were respectively used. The cores were gassed for 0.5 seconds and purged for 7 seconds. The tensile samples were tested at the following times after being removed from the core box: immediately, five minutes, one hour, four hours and twenty-four hours. A Thwing-Albert™ tester shown in Figure 11 was used to measure the tensile strength of the dog bone specimens.

Figure 10 Redford core box machine at the UNI MCC

Figure 11 UNI MCC Thwing-Albert™ Dog Bone Testing Machine

Physical Properties

A LOI was measured on the base sand, reclaimed sand, and cold box core samples. The LOI results are an important characteristic to monitor. These results indicate the amount of impurities on the sand after it has been reclaimed, or to verify the correct amount of binder was used when mixing the individual batches of sand used for sampling. A total of 54 LOI samples were tested using the cold box transverse specimens. One sample from each time tested was split into three different LOI crucibles, totaling nine samples from each batch of sand produced. Approximately twenty grams of the transverse core sample were weighted in an empty ceramic crucible. The furnace was heated to 982ºC and the sample dwelled for a total of one hour until reaching a stable weight. The sample was cooled and weighted again to calculate the LOI percentage.

A dilatometer (Figure 12) was used to characterize the thermal expansion of the sand before and after the reclamation process. The UNI Metal Casting Center sand laboratory performed the testing to determine the expansion of four different samples; new sand, reclaimed sand and two different blends (50/50 and 20/80, new sand to reclaimed sand). The samples were heated to 1650˚C at a heating rate of 15˚C per minute. Cylindrical shaped core specimens were made to a height of 1.5-1.6 inches and 1.1 inches in diameter. A ceramic disk was placed on top of the cylindrical core sample. A single push rod attached to a transducer in contact with this disk to measure the displacement as the sample is heated. Testing was performed under a nitrogen controlled atmosphere.

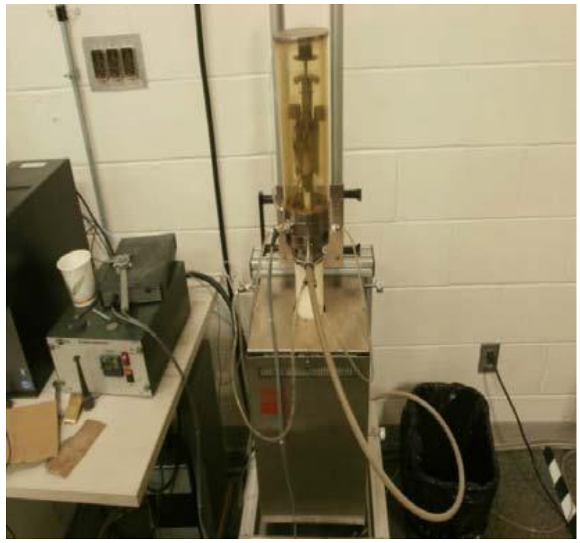


Figure 12 *UNI MCC Dilatometer used to measure the expansion characteristics.*

The round transverse samples were weighed as a group of three before being tested (Figure 13). The purpose of weighing the transverse core samples would help determine if there are differences in the density between the new and reclaimed sand during core production.

Figure 13 *The transverse tensile samples were weighted together as one group*

Sieve analysis and grain fineness number (GFN) of the sand was determined following the AFS 1106-00-S procedure. Determining the GFN at the John Deere Foundry was calculated as shown below in Table 5.

Table 5 AFS GFN Calculation conducted at the John Deere Sand Lab. Showing the calculation for New Sand.

Screen	Individual Retained(g)	Percentage Retained	Multiplier	Product
20	0.00	0.00%	0.1	0.00
30	0.01	0.00%	0.2	0.00
40	2.22	2.22%	0.3	0.66
50	22.57	22.57%	0.4	9.03
70	33.50	33.50%	0.5	16.75
100	29.52	29.52%	0.7	20.66
140	10.49	10.49%	1.0	10.49
200/270/PAN	1.70	1.70%	2.15	3.66
			Calculated GFN	61.25

Grain fineness is used to determine the size distribution of a batch of sand. Different GFN's can affect the physical properties when a binder is applied due to the surface area. A finer or higher GFN sand has a greater surface area resulting in additional amounts of binder to properly coat the sand to maintain a similar strength as compared to a lower GFN sand. To understand the impact to quality and properties of the reclaimed sand, it was important to maintain a similar GFN when performing a comparison. The new and reclaimed sand was split using a 50/50 sand splitter to obtain a representative grain distribution. This was conducted until a sample weight of 2000 grams was achieved.

Acid demand value (ADV) and pH was determined by following the AFS procedure 1114-00S and 5113-00S, respectively. Testing was conducted at the UNI MCC. Determining the ADV and pH can be an indication of the impurities found in the sand which can adversely affect the core properties. This could affect the effectiveness of the catalyst which can change the bench life of the core sand resulting in lower strengths. Depending on these values, special binder formulae considerations may be needed to minimize quality issues.

Figure 14 shows a comparison between the different grain shapes. A coefficient of angularity of 1.0 would be considered a sphere. Results around 1.2 are considered rounded, 1.4 sub-angular, 1.6 angular and compound does not have a factor determined. The UNI MCC conducted the lab test to determine the angularity coefficient following the AFS procedure 1126-00-S.

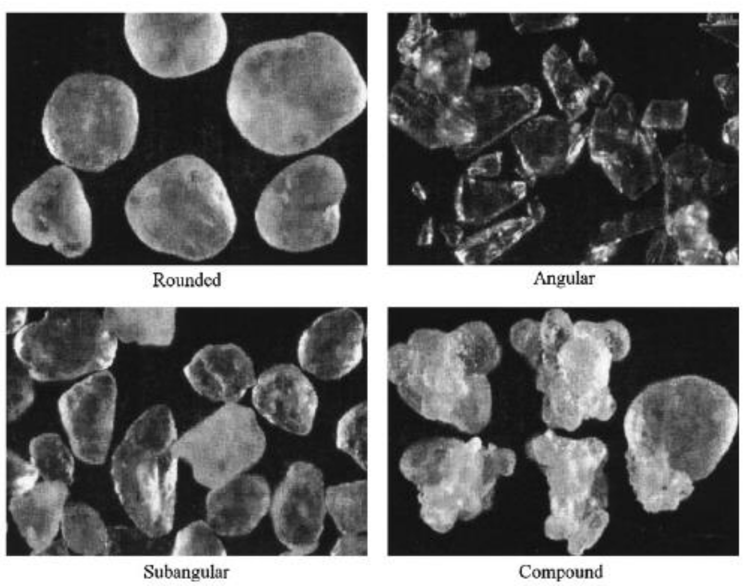


Figure 14 AFS standard comparison grain shape (American Foundry Society, 2003)

Casting Trials

Step-cone analysis was conducted at the UNI Metal Casting Center (MCC). The step cone is a cylindrical casting which has a series of steps that increase in diameter. These steps either increase or decrease the sand-to-metal ratio which can evaluate how the core will withstand against penetration and veining defects. The silica sand step-cone molds were made from a Bio-Urethane binder system using a continuous no-bake mixer. The two-part single molds measured 38x38x19cm for the cope and 38x38x8cm for the drag. The step-cone cores were produced using a phenolic urethane binder system with both reclaimed and new sand. Two cores were produced for each sand type, creating a total of four castings. An example of the mold and step-cone core is shown below in Figure 15. The two castings from each sand type were evaluated for veining and penetration defects. The higher index value indicates a higher number of defects, while a lower value indicates lesser defects. Veining is calculated by totaling the number of "veins" on each step-cone level. Penetration is more subjective depending on the person performing the test but is graded depending on the amount of penetration observed on each step of the step-cone casting. An example of a sectioned step-cone casting with veining and penetration defects is seen in Figure 16.

Figure 15 The UNI MCC Step-Cone Pattern and Step-cone Mold and Core. (Ravi, 2014)

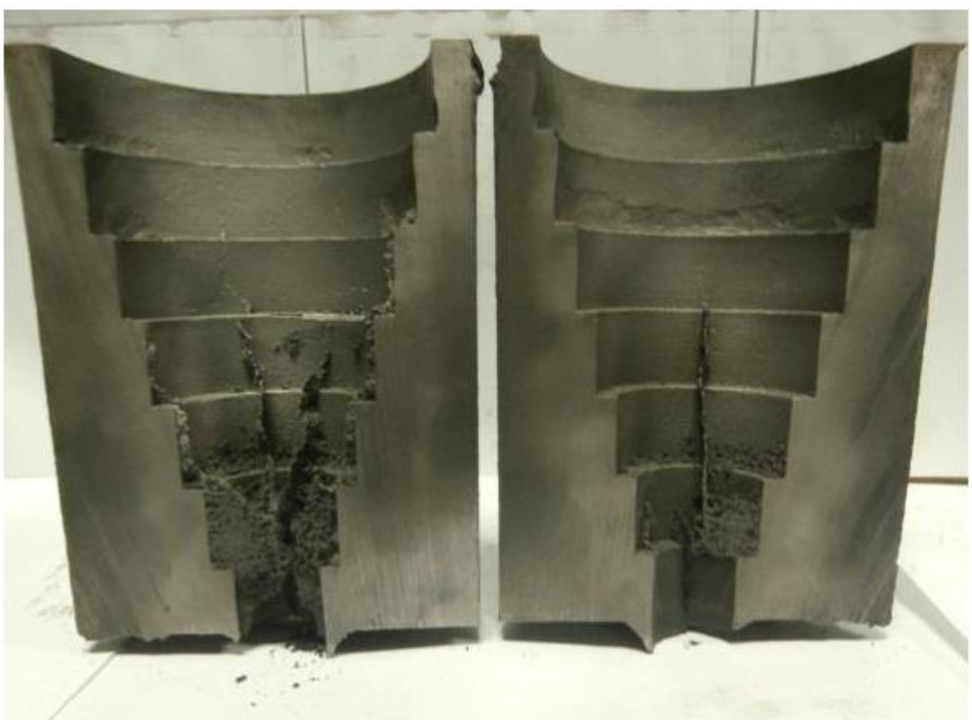


Figure 16 Example of a sectioned step-cone casting, showing veining and penetration defects.

The step-cone molds poured at the UNI MCC used a standard gray iron chemistry. The metal was melted in a 154kg high frequency coreless induction furnace. The metal was heated to 1510ºC, the slag removed, and a chemistry sample poured. The metal was tapped into a heated transfer ladle. The step-cone molds were poured targeting a temperature of 1454ºC, and a target pour time of ten-to-twelve seconds. Each step-cone cast weight was approximately 15kg.

The cores were put through a production trial at the John Deere Foundry where they were compared with cores made from new sand. The core selected for this study had a high metal-to-core ratio and had a history of sand defects requiring additional grinding operations to remove the defects. Visual inspections of the castings were performed to observe if any major differences between the two types of cores. Specifically, veining and penetration defects, burn-on sand and gas defects. A standard gray iron chemistry was used with a pouring temperature of 1400ºC. Ten castings were used for this casting trial.

CHAPTER 4

ANALYSIS OF RESULTS

The results below expand on the prior research conducted at the UNI MCC presented in Chapter 2. Similar sand tests were performed and compared, along with different types of sand testing that all compliment the previous research. After reviewing the UNI MCC results, the remaining sand was sent to the John Deere Foundry to perform an internal analysis that is presented in this Chapter.

Stereomicroscope Sand Images

Images of new, overflow and reclaimed sand were documented using a stereomicroscope observed in Figure 17. There are some slightly discolored sand grains for the new sand, but most of the particles are clear or transparent. There is a drastic difference in appearance with the overflow green sand after it has been through the casting process; including mixing, molding, pouring and shake-out. A dark, dull black color is observed with a couple of new or transparent sand grains mixed in. The source of the transparent or new sand grains in the overflow sand image (Figure 17b) is from the use of cores within the mold. Cores are made from 100% new sand. Depending on the casting being produced (core to metal ratio), a certain amount of core sand (new sand) mixes with the green sand during the shake-out process. The phenolic urethane binder holding the individual sand grains together starts degrading due to the temperature of the liquid metal during pouring and solidification. This sand mixes with the used green sand and is reused to create another mold or is disposed as overflow green sand. The wet reclaimed sand in Figure 17c showed both discolored and transparent sand grains. The sand has a 'shiny' appearance on the surface, comparable to new sand.

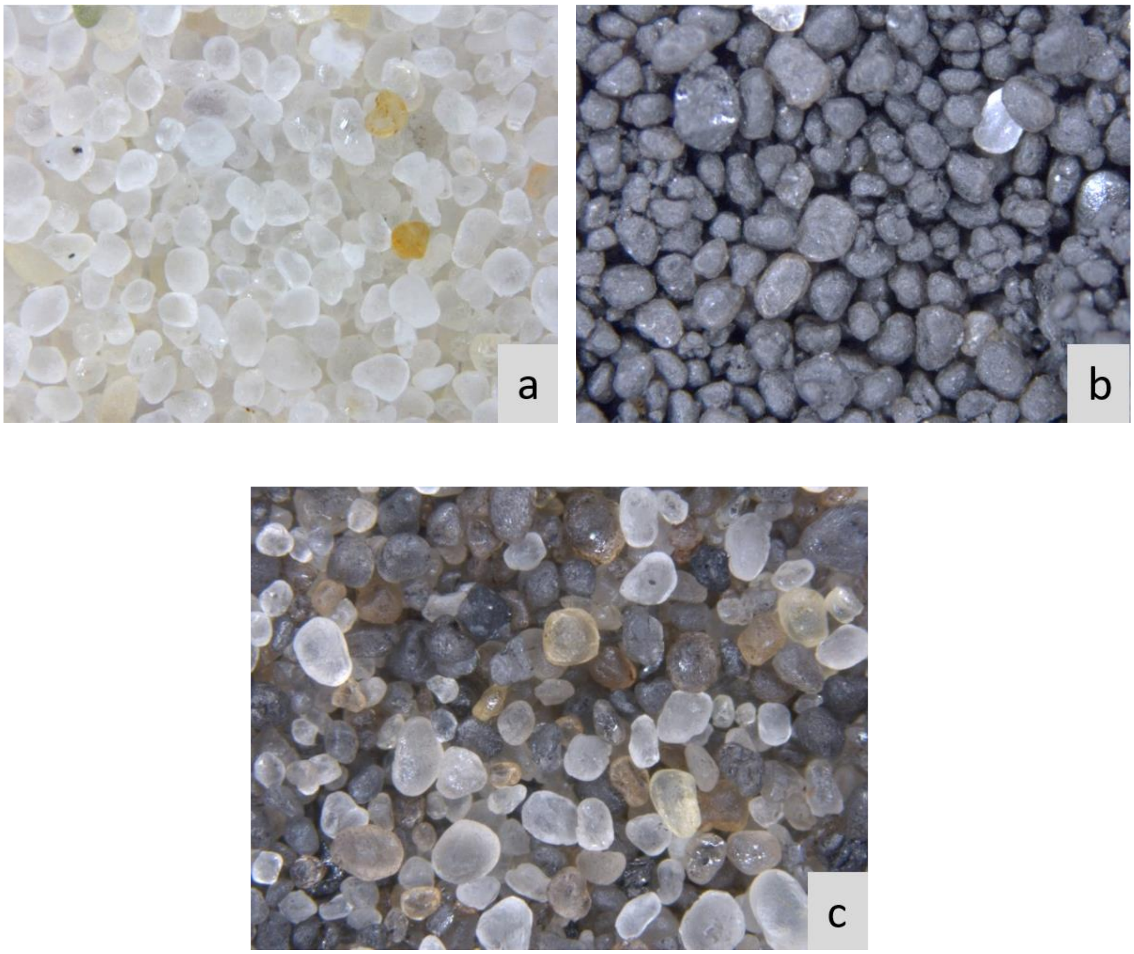


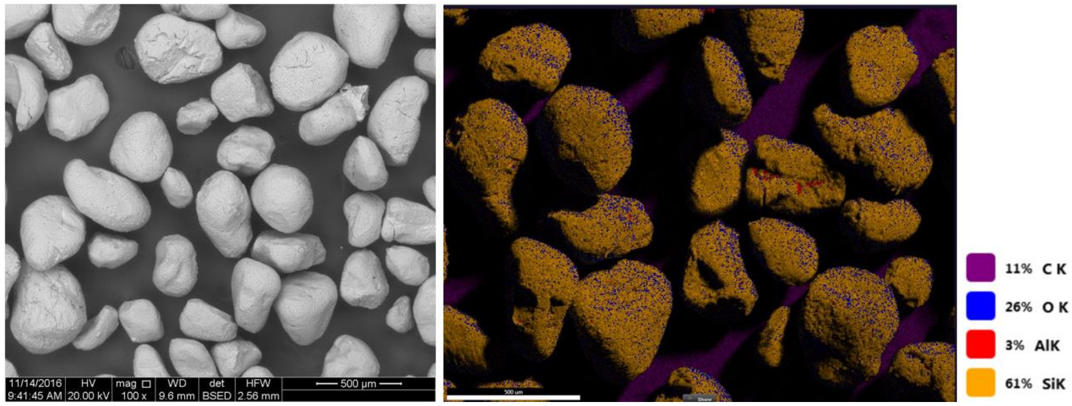
Figure 17 *Stereomicroscope photos at 25X magnification of (a) new sand (b) overflow green sand (c) wet reclaimed sand.*

<u>SEM and EDAX Analyses</u>

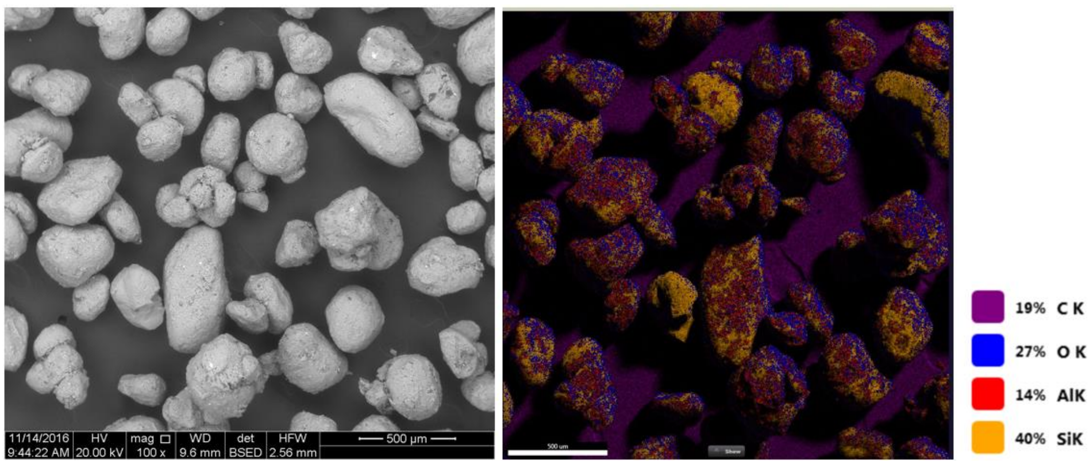
A scanning electron microscope with energy dispersive spectroscopy detector was used to determine the amount of clay coating the sand particles. The same three samples used to document the stereomicroscope images were used; new sand, overflow green sand and wet reclaimed sand. Seen in Table 6, bentonite clay is comprised of approximately 17-21.5% aluminum oxide. Aluminum is an important element of interest for determining the amount of existing or residual bentonite clay.

Table 6 *Typical composition of a bentonite clay (Washigton, DC : U.S. Patent and Trademark Office Patent No. 3779782, 1973)*

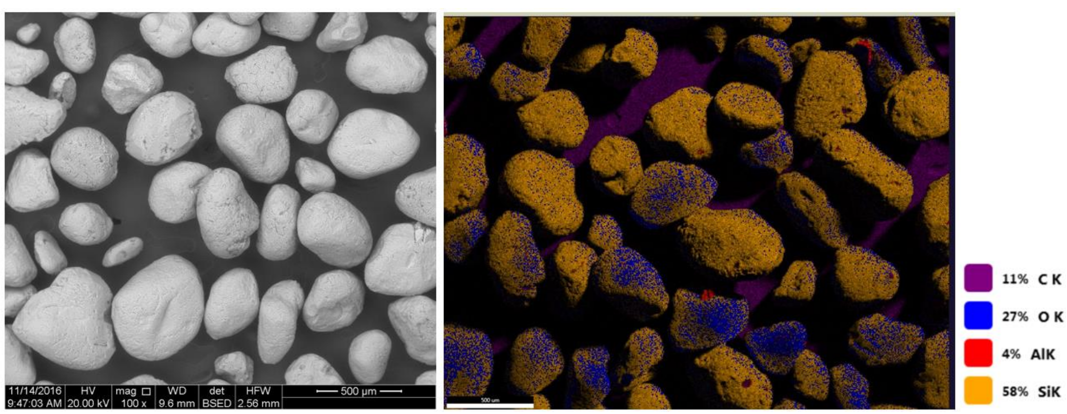
Composition %	% by Weight
Fe	2.9-5.5
Al_2O_3	17.0-21.5
SiO_2	57.0-67.0
Na_2O	1.8-2.7
CaO	1.7-2.6
MgO	1.5-2.8
H_2O	25.0-30.0



(a)



(b)



(c)

Figure 18 SEM images and EDAX mapping results of (a) new sand (b) overflow green sand and (c) wet reclaimed sand.

The results for the new sand showed the aluminum weight percentage to be approximately three percent. There were concentrated areas of aluminum appearing on specific sand grain the aluminum was not randomly distributed.

The overflow sand had an aluminum content of 14%, with a lower percentage of silicon from 61% to 40%. This is due to the clay and other elements coating the silica sand grains causing the silicon to be less apparent. The increase in carbon from 11% to 19% could be for two reasons; 1) the addition of carbonaceous material such as sea coal or lignite, a main ingredient in green sand or 2) the carbon tape used mount the sand grains to the stage is more apparent. The aluminum is randomly distributed across most of the sand grains. The particles which are free of aluminum are likely from core or new sand, comparable to the observations in Figure 17 (a). The SEM image show particles of sand still bound together, and these areas all indicate aluminum on the surface.

The wet reclaimed sand showed very similar EDAX results as the new sand; an aluminum weight percentage of four percent with similar amounts of oxygen, silicon and carbon. The areas of aluminum on these sand grains were also concentrated into specific areas that seem to favor disparities on the surface, such as pits or crack-like features. The wet reclamation process indicates most of the bentonite has been removed from the surface of the sand and is comparable to the new sand results.

AFS Screen Distributions

The AFS grain fineness number was calculated as seen in Table 5 for the samples collected at the John Deere Foundry. The screen distributions results were 61.8GFN for new sand and 61.3GFN for the reclaim (Table 7). Comparing the two results in Figure 19, the most significant difference is the amount retained sand on the 50 and 70 mesh screens. The reclaimed sand had approximately 13% more retained sand on the 70-mesh screen and 13% less on the 50-mesh compared to new sand. The GFN between all tested samples varied less than 2 GFN, including the results from UNI MCC (Figure 3). The UNI MCC results were 60.6 GFN for new sand. The two tests conducted on the reclaimed sand had a 61.8 and 60.1GFN.

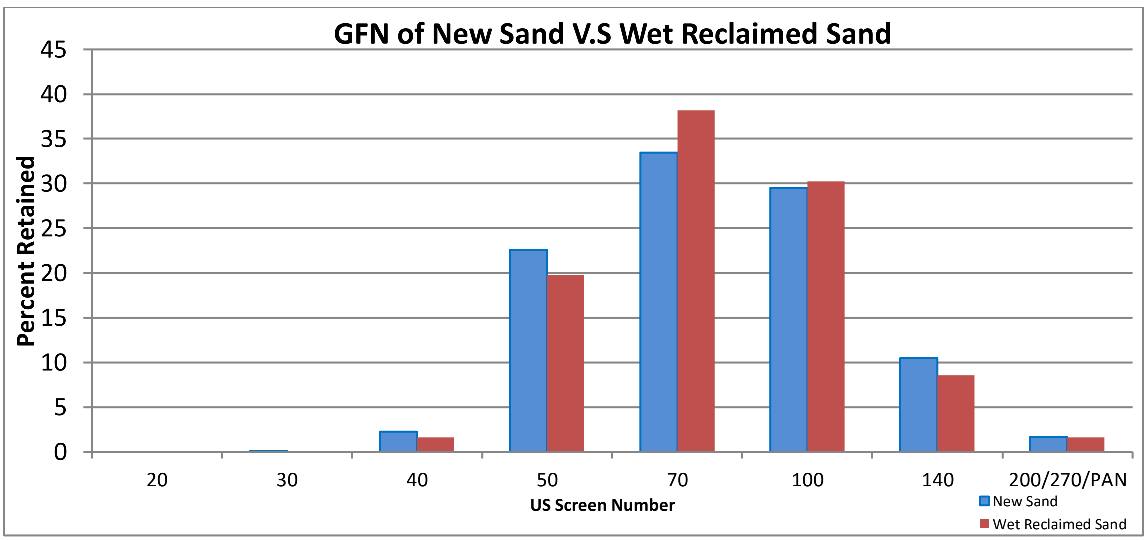


Figure 19 *AFS screen distribution of new and reclaimed sand. John Deere Sand lab results*

Table 7 Calculated GFN results of the AFS screen distribution from Figure 19 and Figure 3.

Sample ID	**AFS-GFN**
UNI MCC	
100% New Sand	60.6
100% Reclaim Sand	61.8
100% Reclaim Sand #2	60.1
JD Foundry	
100% New Sand	61.8
100% Reclaim Sand	61.3

Tensile Results

Tensile properties were obtained to understand the mechanical properties of the sand before and after the wet reclamation process. A total of thirty-six samples were tested for each time; ten, thirty and sixty minutes from when the samples were produced in the core box. The testing was split into three individual batches of sand creating thirty-six data points total for each time tested.

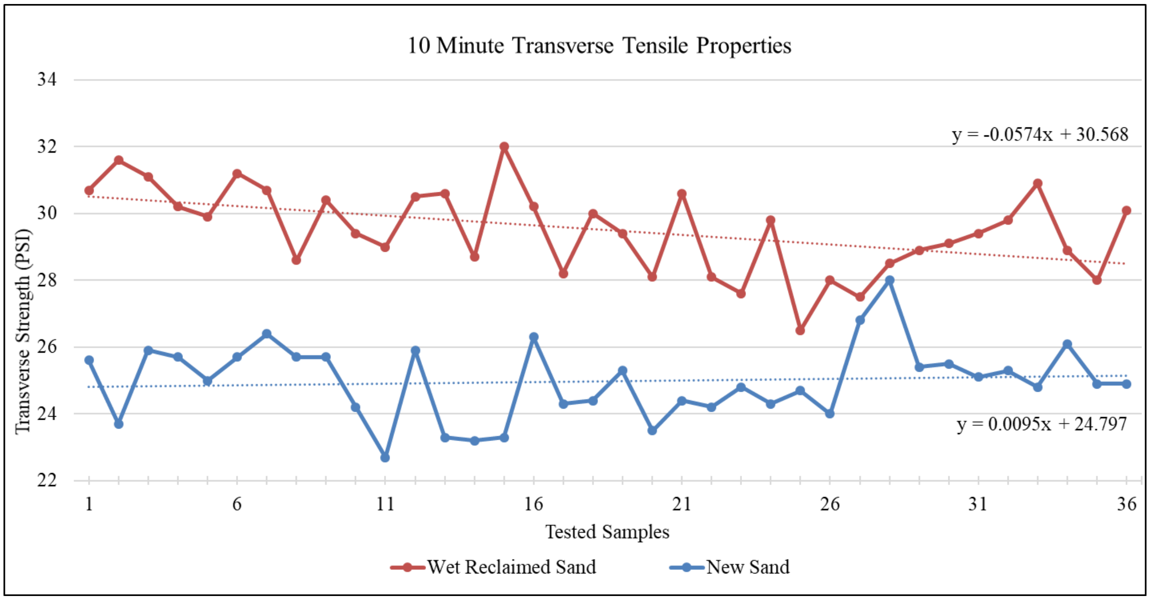


Figure 20 *The plotted ten-minute transverse tensile properties results comparing new and reclaimed sand.*

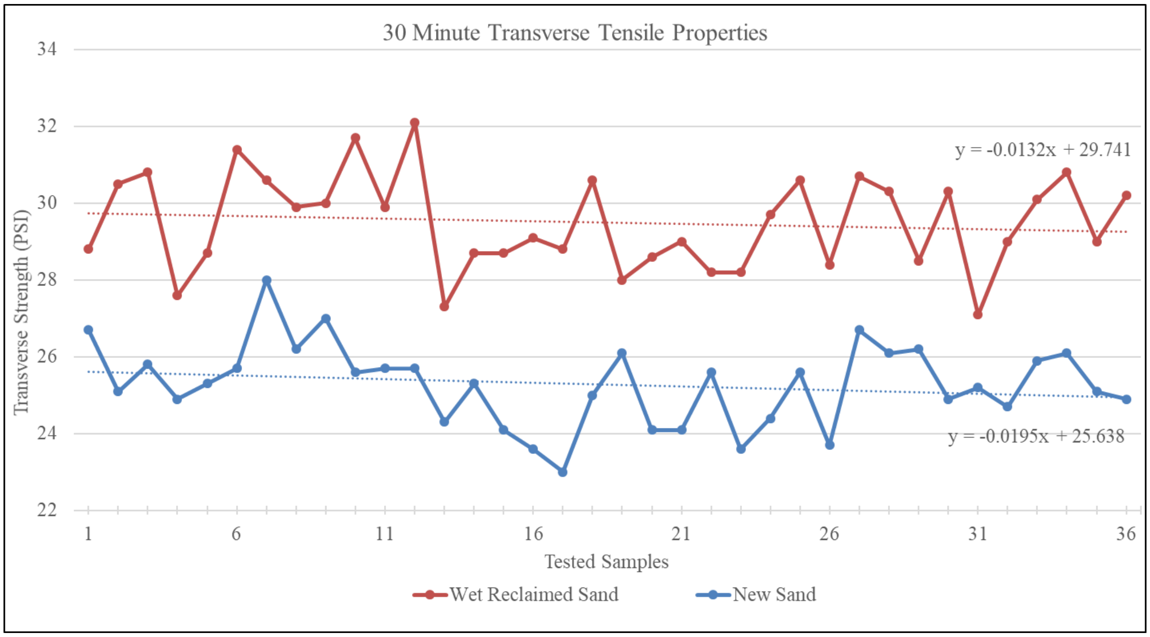


Figure 21 *Plotted 30 Minuted Transverse Tensile Properties*

Figure 22 *Plotted 60 minunte Transverse Tensile Properties*

In Figure 20, the ten-minute transverse tensile properties indicate the reclaimed sand is approximately six psi stronger (averaged properties) compared to new sand. The 30 and 60-minute results show a similar trend, as seen from the averaged tensile properties in Figure 23.

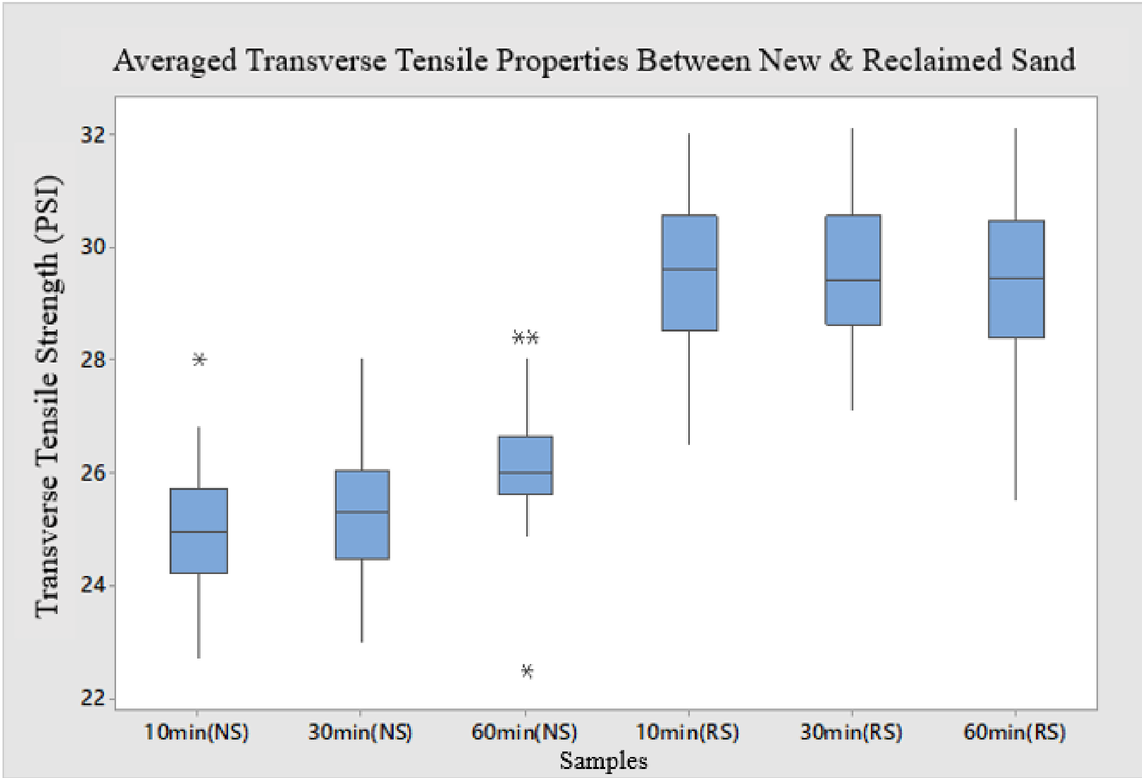


Figure 23 *Averaged transverse tensile properties for new sand (NS) and reclaimed sand (RS). Thirty-six samples for each group were tested.*

The reclaimed samples had more consistent tensile results independent of the time tested. The new sand samples show approximately a one PSI increase in strength between the 10 and 60-minute samples, or a 4% difference. Reclaimed samples showed less than 1% variation between all the averaged tensile results. The new sand samples had a mean of 25.4psi and the wet reclaimed sand was 29.5psi.

The results seen in Figure 4 from the UNI MCC showed a similar trend. The reclaimed sand had higher tensile strengths compared to new sand. The independent lab determined the tensile strength by the ‘Dog Bone’ method (equipment seen in Figure 11), which are tested using a tension force as compared to transverse tensile that is a three-point bending force (Figure 9). The dog bone tensile samples from the independent lab showed a 33% difference between new and reclaimed sand, while the transverse method was 15%. Regardless of the method used to determine the strength of the core, the reclaimed sand had an overall higher core strength.

Transverse Sample Weights

The core box at the John Deere foundry produced three samples at a time, considered to be one group. The core box is seen in Figure 8. The results show a difference in weight between the new and reclaimed sand samples, approximately 2.2grams. The reclaimed sand creates a denser core positively affecting the tensile properties. As the remaining results indicate, this is likely due to the change in surface angularity creating a rounder sand grain. This would also increase the flowability of the sand when producing cores, increasing the density or weight of the samples.

Another contribution towards the increased density could be the screen distribution results. The results from John Deere sand lab showed the amount of retained sand on the 70-mesh screen increased by 14% with the reclaimed sand compared to new sand. On the 50-mesh screen, there was a decrease of 14%. The results for these two screens indicate smaller sized particles for the reclaimed sand. Because of the differences described above, the sand particles are closer together causing the binder to bridge smaller gaps between sand grains, likely contributing towards the increased core strength.

Figure 24 *Measured weight of the transverse cookie samples. Weights represent the group of all three samples together.*

<u>Loss of Ignition Results (LOI)</u>

A total of fifty-four LOI samples were tested. Each sample was tested three times and then averaged. The summarized average results are shown in Figure 25 for all fifty-four samples tested.

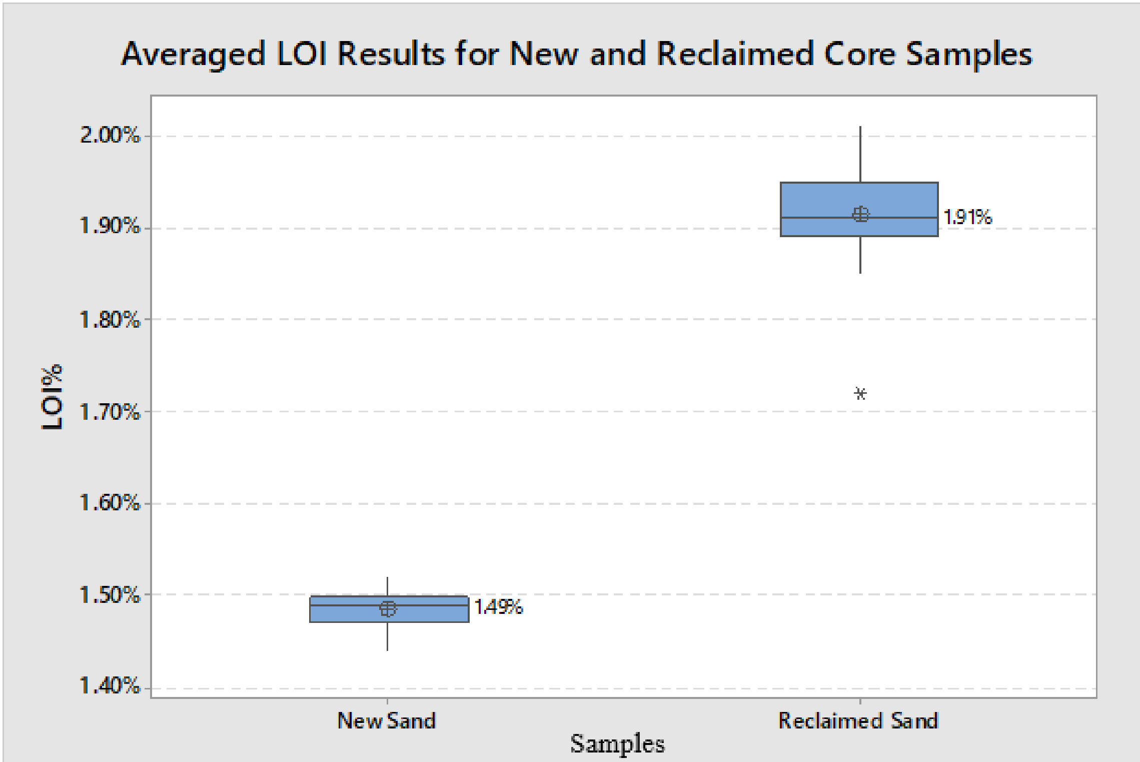


Figure 25 LOI Results from the Core, Transverse Tensile Samples.

The LOI is an important test to understand if the correct amount of binder was applied when mixing the induvial batches of sand. The LOI% for the raw new sand was measured to be 0.065%, while the reclaimed sand was 0.5%. This does indicate the reclamation process leaves some residual amount of material on the sand, which is consistent with the SEM/EDAX observations in (c)

Figure 18(c). The averaged LOI results for the new sand was 1.49% compared to 1.91% with reclaimed sand; about a 0.5% difference which is nearly the same result as the reclaimed sand without the binder.

Casting Trials

Production casting trials were conducted at the John Deere Foundry. As seen in Figure 26, a reclaimed sand core (darker colored core) replaced the normal new sand core. This was a multiple core assembly and the remaining core was made from new sand. This core has a high metal to core ratio making it prone to penetration and veining type defects. Side-by-side comparison were made comparing this specific area using a new or reclaimed core sand. The results from the casting trials showed comparable results between the two sands. There were not any notable increased veining or penetration type defects that would require additional processing time to remove.

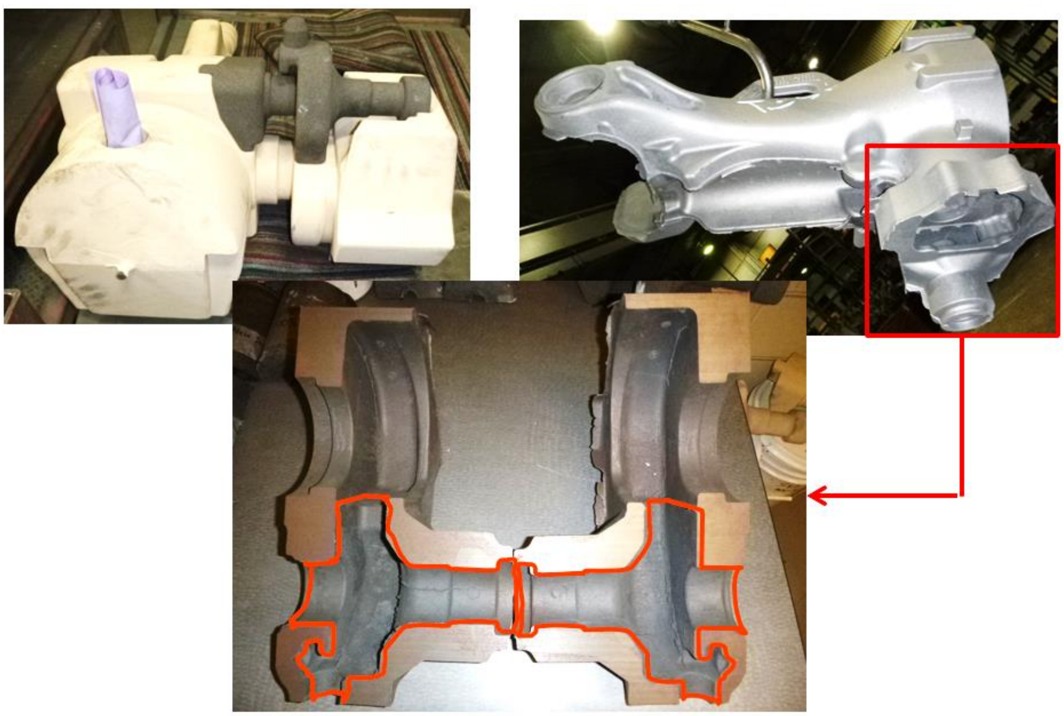


Figure 26 Production casting trials with cores made from reclaimed sand, John Deere Foundry

When the cores were being produced the operators noticed the reclaimed sand to have better flowability. This was noted due to known problem areas on the core that may not properly fill (such as corners) and need to be re-worked by some method (core mud as an example) to ensure a solid core. The operators did not have to perform any type re-work with the reclaimed cores, other than removing the core-fin caused from the core box parting line.

CHAPTER 5

CONCLUSIONS

The proprietary reclamation process does indicate overflow green sand can be used to produce cores that are equal to new sand cores. The results also show there are additional benefits including, increased core strength, denser core, increased flowability for core production, and a reduction of veining type defects when compared to new sand.

Three sand samples (new sand, reclaimed sand and overflow green sand) were analyzed using the SEM with EDAX capabilities to map and determine the amount of existing or residual bentonite clay. After the reclamation process of the overflow green sand, most of the bentonite clay was removed from the surface. The weight percentage EDAX results were comparable to new sand. However, the LOI and ADV results do indicate there is some residual material retained on the reclaimed sand. The reclaimed sand had approximately 0.50% higher LOI. The higher ADV result of 6.317 correlates to the increased pH of 8.130 with the reclaimed sand, while the new sand had an ADV of 0.663 and a pH of 7.003.

The tensile results for the reclaimed sand produced a stronger core while maintaining the same amount of phenolic urethane binder. The averaged results from the UNI Metal Casting Center using a ‘dog bone’ tensile samples showed a 22% difference between new and reclaimed sand. The transverse tensile method results conducted at the John Deere showed a 15% increase in strength. A similar AFS GFN was recorded for both sands, which varied less than 3%.

As the green sand is reused for molding operations, the sand becomes less angular and more spherically shaped. This shape contributes to the increased density and flowability observed with the reclaimed sand. The weight of the transverse tensile samples varied approximately two grams, demonstrating the reclaimed sand ability to produce a denser core. The coefficient of angularity and the surface area both decreased with the reclaimed sand. The reduction in surface area likely contributes to the increased tensile strength. More of the binder can be used to bond the sand grains together instead of coating the individual particles.

The linear expansion results performed at the UNI MCC indicate the reclaimed sand has a lower susceptibility to veining type defects. Previous research has shown that the cause of veining defects is not the expansion of the sand but the contraction after the Alpha/Beta phase transformation. The difference in contraction after the Alpha/Beta phase transformation with new sand was approximately 60%, while reclaimed sand was 20%. The step-cone casting trials showed there were a reduced amount of veining defects compared to new sand. However, there was a slight increase in penetration defects with reclaimed sand during this casting trail. The production casting trials performed at the John Deere Foundry did not indicate an increase in either veining or penetration related defects.

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APPENDIX

SUPPLEMENTAL LAB RESULTS

Table 8 Transverse Tensile Properties of New and Reclaimed Sand

Transverse Tensile Properties (PSI)									
Tag	OB (10min)	30min	60min	Sand Type	Tag	OB (10min)	30min	60min	Sand Type
A	25.6	26.7	25.7	New Sand	A	30.7	28.8	30.1	Reclaimed
A	23.7	25.1	25.7	New Sand	A	31.6	30.5	29.6	Reclaimed
A	25.9	25.8	26.7	New Sand	A	31.1	30.8	32.1	Reclaimed
B	25.7	24.9	28	New Sand	B	30.2	27.6	29	Reclaimed
B	25	25.3	26.2	New Sand	B	29.9	28.7	30.2	Reclaimed
B	25.7	25.7	26.2	New Sand	B	31.2	31.4	32.1	Reclaimed
C	26.4	28	26	New Sand	C	30.7	30.6	29.4	Reclaimed
C	25.7	26.2	25.3	New Sand	C	28.6	29.9	27.9	Reclaimed
C	25.7	27	25.7	New Sand	C	30.4	30	29.8	Reclaimed
D	24.2	25.6	28.4	New Sand	D	29.4	31.7	31.6	Reclaimed
D	22.7	25.7	25	New Sand	D	29	29.9	30.5	Reclaimed
D	25.9	25.7	25.8	New Sand	D	30.5	32.1	30.9	Reclaimed
A	23.3	24.3	25.7	New Sand	A	30.6	27.3	29.9	Reclaimed
A	23.2	25.3	25.5	New Sand	A	28.7	28.7	28.5	Reclaimed
A	23.3	24.1	24.9	New Sand	A	32	28.7	30.3	Reclaimed
B	26.3	23.6	27.4	New Sand	B	30.2	29.1	27.4	Reclaimed
B	24.3	23	26	New Sand	B	28.2	28.8	29.2	Reclaimed
B	24.4	25	27.1	New Sand	B	30	30.6	30.1	Reclaimed
C	25.3	26.1	26.4	New Sand	C	29.4	28	28.3	Reclaimed
C	23.5	24.1	26.4	New Sand	C	28.1	28.6	25.5	Reclaimed
C	24.4	24.1	26	New Sand	C	30.6	29	31.7	Reclaimed
D	24.2	25.6	25	New Sand	D	28.1	28.2	29.4	Reclaimed
D	24.8	23.6	24.9	New Sand	D	27.6	28.2	28.4	Reclaimed
D	24.3	24.4	24.9	New Sand	D	29.8	29.7	28.4	Reclaimed
A	24.7	25.6	22.5	New Sand	A	26.5	30.6	30	Reclaimed
A	24	23.7	25.6	New Sand	A	28	28.4	27.9	Reclaimed
A	26.8	26.7	28	New Sand	A	27.5	30.7	31	Reclaimed
B	28	26.1	28.4	New Sand	B	28.5	30.3	30.3	Reclaimed
B	25.4	26.2	26.5	New Sand	B	28.9	28.5	28.5	Reclaimed
B	25.5	24.9	26.1	New Sand	B	29.1	30.3	30.5	Reclaimed
C	25.1	25.2	26.3	New Sand	C	29.4	27.1	29.2	Reclaimed
C	25.3	24.7	25.9	New Sand	C	29.8	29	27.1	Reclaimed
C	24.8	25.9	26.4	New Sand	C	30.9	30.1	29.2	Reclaimed
D	26.1	26.1	27	New Sand	D	28.9	30.8	31.9	Reclaimed
D	24.9	25.1	25.7	New Sand	D	28	29	28.2	Reclaimed
D	24.9	24.9	26.8	New Sand	D	30.1	30.2	29.5	Reclaimed

Table 9 LOI Results from Transverse Tensile Specimens

LOI Results					
	Date	**LOI-1**	**LOI-2**	**LOI-3**	**Average**
New Sand	11/17/2014	1.49%	1.50%	1.49%	**1.49%**
New Sand	11/17/2014	1.52%	1.44%	1.49%	**1.48%**
New Sand	11/17/2014	1.51%	1.52%	1.52%	**1.52%**
New Sand	11/17/2014 #2	1.46%	1.50%	1.47%	**1.48%**
New Sand	11/17/2014 #2	1.47%	1.46%	1.49%	**1.47%**
New Sand	11/17/2014 #2	1.46%	1.47%	1.49%	**1.47%**
New Sand	11/18/2014	1.45%	1.48%	1.48%	**1.47%**
New Sand	11/18/2014	1.50%	1.47%	1.52%	**1.50%**
New Sand	11/18/2014	1.48%	1.47%	1.50%	**1.48%**
Reclaimed	11/20/2014	1.97%	1.96%	1.97%	**1.97%**
Reclaimed	11/20/2014	1.94%	1.97%	2.01%	**1.97%**
Reclaimed	11/20/2014	1.94%	1.95%	1.97%	**1.95%**
Reclaimed	11/21/2014	1.91%	1.91%	1.85%	**1.89%**
Reclaimed	11/21/2014	1.90%	1.72%	1.85%	**1.82%**
Reclaimed	11/21/2014	1.91%	1.89%	1.87%	**1.89%**
Reclaimed	12/5/2014	1.90%	1.92%	1.91%	**1.91%**
Reclaimed	12/5/2014	1.92%	1.88%	1.94%	**1.91%**
Reclaimed	12/5/2014	1.89%	1.91%	1.92%	**1.91%**

Table 10 Averaged Transverse Sample Weight of Three Samples

Transverse Tensile Weights					
#	**Reclaimed Sand**	**New Sand**	#	**Reclaimed Sand**	**New Sand**
1	77.7	75.53	**19**	78.07	75.93
2	78.08	75.67	**20**	77.83	75.71
3	77.79	75.53	**21**	77.25	74.96
4	77.51	75.94	**22**	78.24	76.09
5	77.86	75.74	**23**	78.03	76.03
6	77.66	75.77	**24**	78.14	76.04
7	77.83	76.04	**25**	78.27	75.95
8	77.81	75.99	**26**	77.9	76.12
9	77.82	74.96	**27**	78.27	75.93
10	77.98	75.72	**28**	78.58	75.81
11	77.8	75.87	**29**	78.73	76.03
12	78.04	76.15	**30**	78.39	75.59
13	77.99	75.92	**31**	78.74	75.91
14	78.12	75.98	**32**	77.84	75.9
15	77.86	76.26	**33**	77.99	75.95
16	77.92	75.77	**34**	80.04	75.66
17	78.25	74.92	**35**	78.41	76.05
18	78.2	75.77	**36**	78.41	75.95