Foundry 4.0 – Smart Precision Casting Needs Viscosity Control of Ceramic Slurries

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Investment Casting– The Catalysts of Growth

Investment casting process, also known as lost wax process, is relatively simple, which enables rapid production rates while ensuring consistent dimensional accuracy. It offers weight reduction, less machining, improved delivery time and lower inventory carrying costs, making it one of the most popular production methods for metal parts today. The variety of parts manufactured by investment casting is ever increasing with growing complexities of requirements from the oil & gas drilling, automotive, aircraft, defence, medical and military industries.

Ceramic Slurry for Shell Building – Viscosity is Crucial to Getting Reliable Slurry

Ceramic shell, formed by dipping the wax assembly multiple times in the ceramic slurry is critical to achieving precise, reproducible parts. To ensure consistent shells, it is vital to have consistent ceramic slurry. Viscosity is one of the key properties of the ceramic slurry which defines the overall thickness and adhesion of the multiple coats during shell formation. After coating, the ceramic shell is fired to attain ultimate strength, dimensions and morphology as finished products. Yields of usable products are dependent on reliable shells.

The quality of the ceramic shell depends on the slurry composition and the process by which it is built. Typical ingredients in an investment casting slurry include: colloidal silica, water and/or polymers, wetting agents, anti-foaming agents, and refractory flours. The raw materials (refractory, binder, wetting agent, and antifoam) used to make slurry play a major role in determining the overall final ceramic shell characteristics. Suitable choice and good mixing of ceramic materials can lead to smooth surface finish, and high accuracy of the metal castings.

Slurry Viscosity

A good slurry composition alone cannot guarantee production of smooth and defect free shell if the slurry is prepared in an inadequate manner. Slurry quality control is one of the most important operations of the investment casting process, with viscosity control of the slurry being key to ensure compliance. Key points on how slurry viscosity affects the investment casting process are:

- Slurry viscosity depends on the composition (filler to binder ratio) as well as the aging time and is an important indicator of the slurry stability. It is initially high when slurries are mixed; however, as mixing continues and the refractory material is wet and air is released, the viscosity decreases and asymptotically approaches a stable value.
- Surface finish will be an important characteristic of the casting, therefore the surface quality of ceramic shell for investment casting of metal alloys must be adequate. The surface finish is highly dependent on the viscosity of the primary slurry and the overall stability of the slurry mixture.
- Viscosity is an effective indicator of the particle size distribution of the slurry. Particle size distribution variability of ceramic flour (powder) can affect slurry properties including slurry density, rheology, and coating thickness. Shell properties that can be affected are permeability, thermal characteristics, thickness, edge coverage, and strength. For critical applications like Titanium and DS/SC casting, control of particle size can mean the difference between success and failure.
- Continuous process control is essential for achieving target bending strength of the investment shell. Increase in slurry viscosity increases the bending strength of the investment shell, but decreases beyond a limiting viscosity attributed to larger content of refractory flour to binder content.

In order to have an effective shell building process and so as not to waste materials and optimise energy usage, it is highly desirable that the slurry viscosity be regulated automatically to a pre-set value. Real-time, in-line viscosity monitoring and control in the mixing and coating process is essential to improve performance and reduce costs. Process operators realise the need of a viscometer that monitors viscosity and temperature, and could use temperature-compensated viscosity as the key process variable (KPI) to ensure consistency and reduce reject rates of the final castings plus avoid seasonal fluctuations affecting the slurry preparation.

Ensuring Top-Quality Products – Viscosity Affects Slurry Coating During Shell Formation

There are four significant factors that make viscosity management important in investment casting application:

1. **Investment shell and casting quality:** Poor coating quality can adversely affect the desirable properties of the investment shells – surface roughness, thermal conductivity, chemical reactivity, permeability and shell strength

Figure 1: SRV (Wide Range Inline Viscometer)

Figure 2: SRD (Inline process density meter and viscosity meter)

in turn affecting the quality of the investment castings.

2. **Reducing costs by reducing waste:** Over-mixing can not only affect the quality of end product but waste ingredients, raw materials, time and energy. Viscosity management in the mixing process can identify the endpoint reliably and accurately.
3. **Efficiency:** Hassle free, real time monitoring of mix viscosity eliminates the costly and time-consuming laboratory analysis, which often results in delayed response to changes in the slurry properties. Ensuring consistency throughout the coating process significantly reduces reject rates saving cost and time and assists in continuous casting processes.
4. **Automation:** Automatically monitoring and controlling slurry preparation and coating process eliminates a manual task that is prone to errors and enables operators to focus on the quality of the final product.

Advantages Of Inline Viscosity Monitoring – Reducing Key Shell Defects

Viscosity control can help alleviate the frequency of defects in the coating process – sticking and picking, twinning, peeling, splitting, cracking, roughness, blistering, bridging, surface erosion and reduce poor flow characteristic which lead to poor shell build resulting in casting defects.

With continuous online viscosity monitoring, shell formation can be controlled more effectively, therefore significantly improving the metallurgical properties of the final product.

Process Monitoring and Control Challenges

Engineers and operators in the investment casting industry recognize the need to monitor viscosity for top-quality shell manufacturing, but making that measurement has challenged process engineers and quality departments over the years.

Challenges with traditional viscosity measurements

Traditionally, operators in investment casting industry have measured the viscosity of slurry using the Zahn flow cup. The measurement is reported as the time elapsed for the cup volume to flow through a hole in the bottom of the cup. The end point of the test must be chosen so that it is consistent from test to test. The procedure is messy and time-consuming. It is inaccurate, inconsistent and non-repeatable even with an experienced operator. In the continuous casting process, the interval sampling causes excessive delays. The viscosity of slurry can't be adjusted in real time. Besides, the drum containing the slurry are open; due to changes in ambient temperature, humidity and other factors, such as temperature, dry climate, solvents are likely to be volatile, so cup-based viscosity measurement technique becomes ineffective.

Viscosity and other characteristics relatable to it (e.g. shear rate and weight percent of solids) vary with depth in a tank containing substantial amounts of ceramic slurry, conditions of movement of slurry (generally induced to maintain homogeneity), capture by cast parts and replenishment or adjustments. There are several approaches to measuring viscosity online through instrument probes inserted into the casting bath at various depths, but they have been prone to drift and error over the course of casting operations and some may need frequent removal, cleaning or replacement, down time and recalibration of the probes and instruments. There are some probes which can be cleaned in situ, but they are subject to malfunction due to exposure to undesirable and variable coating of transducer elements.

Slurry coating systems need the ability to accurately measure the actual viscosity of the ceramic slurry or other material. In particular, it would be desirable to provide the systems with an in-line viscometer to be used with a closed-loop control system for monitoring and controlling the coating processes in shell building.

Smart Foundries – Drivers for Casters' Embrace of Industry 4.0 and Digitalization

Temperature and humidity fluctuations, mixing equipment condition, substrates, solvents, formulations, line-integration, machine interactions and time of mixing are few of the many parameters which can alter the ceramic slurry quality in investment casting across batches. In foundries, the downtimes and delay in deliveries involved due to rejects can hurt the profitability seriously. But what if there was a system which can continuously monitor the product quality and consistency, and could take corrective actions automatically and adaptively without disrupting the whole operation?

Technologies required to deliver such transformational changes in the foundry now exist. Once the manufacturer invests in process monitoring equipment, the current

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industrial control systems are well developed to be able to use the viscosity data from the processes effectively for operations.

The key value drivers of embracing real-time inline viscosity monitoring equipment by manufacturers and system integrators operating in ceramic slurry coating for shell building:

Automated corrective actions for ensuring product consistency. Closed control loops through sensor-based, in-line quality inspection reduce waste and increase yield through early process deviation detection, root cause analysis, and automatic correction.

More agility in dealing with new product variants in production, compliance and product provenance. Casting manufacturers get a more accurate picture of how the new slurry formulations will behave and how they might need to adjust current systems and control parameters.

Big data provides robust evidence to base decisions for greater efficiency. The data provided by the process monitoring equipment enables them to tweak various process parameters and optimise the manufacturing process. Interconnection and information transparency allow for operators to make decisions both inside and outside of production facilities, thus enabling decentralization of decisions.

Higher customer satisfaction and adapting to customer requests. Industry 4.0 solutions can impact casting companies by driving closer interactions with their customers. The technology, data, and information that can help transform manufacturing operations can also make processes and systems more responsive to customer needs.

An Inline Sensor for Easy Integration in the Slurry Preparation Drum

Rheonics sensors are plug and play automation. The inline viscometer can be installed in any slurry drum with a simple tank mount. The whole operation of installing the sensor and starting to see real-time measurement of viscosity takes less than 30 minutes. Rheonics sensors have built-in temperature measurement, ensuring both viscosity and temperature of the slurry mix is monitored at all stages – from mixing to coating. Viscosity readings can be compensated for temperature, which is essential for ensuring consistent production through typical daily and seasonal temperature variations.

Figure 3: Turnkey integrated solution - Rheonics slurry monitoring and control system

The viscometer is hermetically encapsulated and insensitive to external machine noise - hence performance is unaffected by turbulence and fluid non-homogeneity. Automated online viscosity measurement through SRV or an SRD eliminates the variations in sample taking and lab techniques. The sensor is installed in the mixing/coating tank, continuously measuring the formulated system viscosity (and density in case of SRD). Coating consistency during shell building is achieved through automation of the dosing system through a process controller based on real-time viscosity, and temperature measurements.

During slurry preparation process prior to coating (and even during coating by dipping), the mixing process can be monitored with Rheonics sensors, which can verify if solids content & homogeneity (stability) are optimal, without worrying about a myriad of factors which might affect them. Inline viscosity management with the Rheonics sensors can help alleviate most common issues like ceramic inclusion, crack, distortion, flash, misrun, shrinkage, slag inclusion and cold shut that can negatively impact the quality of final products.

Rheonics offers an integrated standalone viscosity, density and pH monitoring and control system. The Rheonics Slurry Monitoring and Control system uses inline viscometers and inline pH probes to monitor slurry viscosity, temperature and pH in real-time. Correction valves are operated to add the correct dose to ensure absolute control of the slurry characteristics through-out the mixing and coating process.

As manufacturers seek to become more agile in adapting to industry's requirements, they understand the need to invest in R&D activities and advanced process control technologies to develop new formulations with tailored characteristics. Rheonics inline viscometers empower investment casting manufacturers with capabilities for shell-building of top quality and great variety, with least involvement of operators on factory floor – a significant advantage over other measurement alternatives or process control solutions. Data provided by the Rheonics viscometers and integrated solutions helps to accelerate learning curves and accommodate more frequent slurry composition changeovers, contributing to a more resource-efficient, economical and greener manufacturing process. Inline blending with continuous viscosity monitoring solutions solves

major challenges of batch production processes such as losses during product changeovers and inefficacies of material handling in a recipe-based approach. It supports scaling up of operations with ease.

Conclusion

With huge application areas and growing demand from the end-use sectors, this industry is looking for new ways to improve efficiency, lead time, and capacity utilization. Industry leaders across sectors are moving towards adoption of more advanced technologies such as automation, industrial internet of things (IIoT) and simulation techniques. Inline viscosity monitoring solutions help investment casters achieve advanced process control over the slurry preparation (mixing) and coating process to build top-quality and defect-free shells with more real-time insights into their processes; and reap the benefits of Industry 4.0 and automation such as reduction in lead times, enhance capacity utilisation, reduce scraps and wastes and optimize efficiency.

The sensors - SRV and SRD are being used in slurry tanks for investment casting application across the globe. These sensors have undergone extensive field and internal testing, and qualification procedures for operation with fluids generally used in this application. Our in-house application engineering team gives machine builders advanced knowhow to achieve seamless integration of our sensors in their system and help provision casting quality control data to their end users through on-premise, edge or cloud connectivity.

Unique benefits with the Rheonics inline online viscometer SRV for slurry mixing and coating applications include:

- Operates accurately in almost all coating systems with a broad range of composition/formulations
- Maintains the set slurry viscosity in mixing tanks regardless of temperature and humidity fluctuations, mixing equipment condition, substrates, solvents, formulations or dosing of colloidal silica, water and/or polymers, wetting agents, anti-foaming agents, and refractory flours
- Rugged, hermetically sealed sensor head. Sensor probe can be cleaned inline with all standard CIP/SIP processes, or with a wet rag manually, without the need for disassembly or re-calibration
- All wetted parts are 316L stainless steel – no corrosion problems
- Certified under ATEX and IECEx as intrinsically safe for use in hazardous environments
- Wide operational range and simple integration – Sensor electronics and communication options make it extremely easy to integrate and run in industrial PLC and control systems

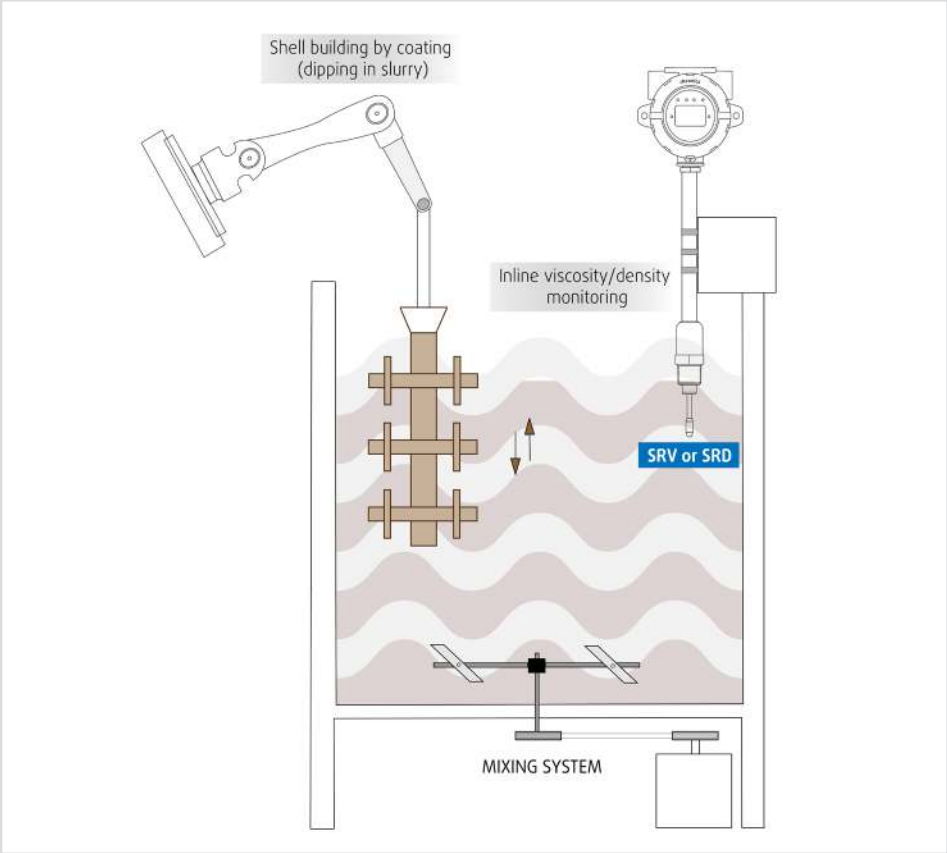

Figure 4: SRV/SRD in ceramic slurry mixing tanks during mixing and coating for shell building - Schematic with possible mount location of the sensor

For more information, contact info@rheonics.com or visit rheonics.com.

References

1. Bundy, J., Viswanathan, S. (2009) "Characterization Of Zircon-Based Slurries For Investment Casting" Inter Metalcast 3, 27–37. https://doi.org/10.1007/BF03355439
2. Singh, B., Kumar, P., Mishra, B.K., "Evaluation Of Primary Slurry Used In Ceramic Shell Investment Casting Process" International Journal of Emerging Technology and Advanced Engineering, ISSN 2250-2459, 2012, Volume 2, Issue 10.
3. Yamagata, H. (2005) "11 - The Turbocharger And The Exhaust Manifold" The Science and Technology of Materials in Automotive Engines, 248-260. https://doi.org/10.1533/9781845690854.248
4. Kaila, V., & Engg, S. (2014) "Optimization Of Ceramic Shell Mold Materials In Investment Casting" International Journal of Research in Engineering and Technology, 03, 30-33. https://doi.org/10.15623/IJRET.2014.0310005
5. SRV inline viscometer: https://rheonics.com/products/inline-viscometer-srv/
6. SRV operating principle: https://rheonics.com/whitepapers/