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Surface Finish Requirements & Inspection

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ABSTRACT

In new casting projects, a detailed discussion about surface finish is infrequent. Surface finish requirements are usually implied in discussions and loosely referenced as an RMS or Ra value. Little discussion occurs about the functional reason for the finish unless it is an airflow requirement in a turbine engine casting. There is usually no supplementary discussion or agreement between the casting purchaser and the casting manufacturer beyond this. As a result, misdirection ensues due to the fact that little understanding exists about surface finish or the implications of attaining stated levels of quality. This arrangement can lead to misunderstandings later in qualification and production. There exists a gap, where casting designer/purchaser assumes surface finish requirements including the notion that all inspection requirements (RMS and Ra) are interchangeable and that inspection technologies (comparison method and profilometer method, for example) are interchangeable and must meet the same fixed requirement. Oftentimes, the designer/purchaser requires RMS using the comparison method and then errantly may switch to the profilometer method expecting similar results to the comparison method, which do not occur. Many times, the metalcaster agrees because they are unfamiliar with the specific surface finish requirements and assumes that the designer must be correct in their request. This can cost the metalcaster in terms of excessive surface finishing, inspection time, cost, labor and unnecessary surface rework. This paper discusses the topic of surface finish for the casting purchaser and casting manufacturer. Surface technology, surface finish attainment, and surface finish inspection are included with an added section about problems in additive manufacturing relative to surface roughness and surface finish/inspection. Provided is a detailed analysis which includes a case study, a surface engineering discussion, process data, an inspection improvement summary, photos and a practical guide to manage this topic. This paper represents a collaboration with and data from Impro foundries where customer situations were successfully worked through. It is hoped that the reader gains valuable information to successfully handle this topic in their own workplace where the situation is turned from "production stopping" to smooth production.

Keywords: root mean squared, RMS, arithmetic average, surface finish, surface texture

INTRODUCTION

The specific purpose, of this paper is to share details about surface texture and inspection; its processing methods, inspection methods, and the final product quality. It is hoped that the reader will gain a greater understanding of a product's surface needs and be confident in specifying surface texture requirements on a casting drawing.

What is a surface? It is a boundary that separates one object from another object, in space. Everything has surfaces and the surfaces impact the function of the part. Texture is the word to use, not roughness. Roughness already characterizes something (Fig.1). Texture is deviation from a perfectly flat part surface.[1,2] We all have a concept of texture or roughness, but it is dependent on the part and its application. For example; the texture of a ball bearing surface and the waviness of the moon's surface are very dissimilar, and are different to characterize, specify and inspect (Fig. 2).

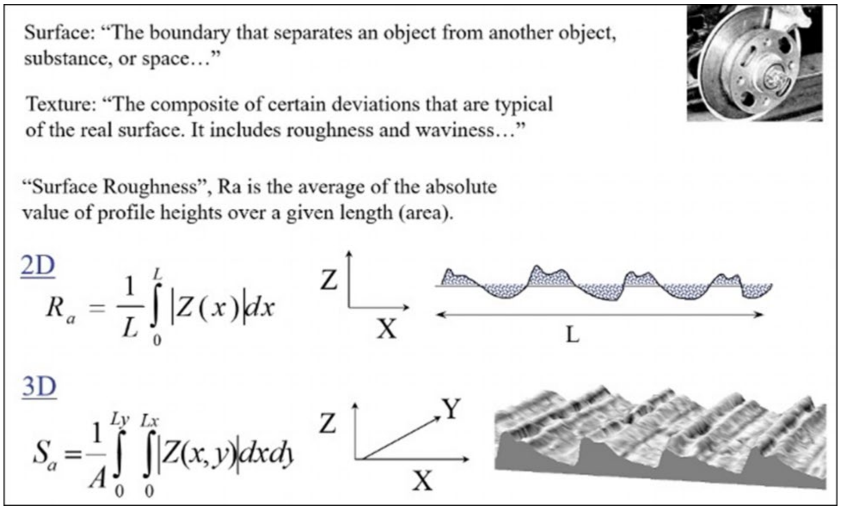


Figure 1. Surface, texture and surface roughness are defined in this illustration.[1](Artwork courtesy of Udemy Instructor, Donald Cohen.)

PROCESS	um	uin.
Sand Casting	12.5-25	500-1000
Sawing	3.2-25	128-1000
Planing/Shaping	0.8-25	23-1000
Forging	3.2-12.5	128-500
Drilling	1.6-6.3	64-250
Milling	0.8-6.3	32-250
Boring/Turning	0.4-6.3	16-250
Broaching	0.8-3.2	32-128
Cold Roll/Draw	0.8-3.2	32-128
Die Casting	0.8-1.6	32-64
Course grinding	0.4-1.6	16-64
Fine Grinding	0.1-0.4	4.0-16
Honing	0.1-0.8	4.0-32
Polishing	0.05-0.4	2.0-16
Lapping	0.025-0.4	1.0-16
COMPONENTS		
Gears	0.25-10	10-400
Journal Bearings	0.12-0.5	5.0-20
Roller Bearings	0.025-0.4	1.0-5.0

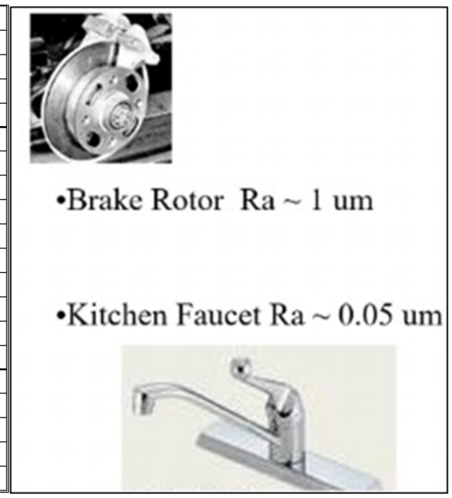


Figure 2. Surface measurement values are listed by manufacturing process and component.[1](Artwork courtesy of Udemy Instructor, Donald Cohen.)

When defining the spatial wavelength or filtering, the shorter spatial wavelengths is roughness (i.e., on the surface of a ball bearing, or the "grass"). The term waviness is used for the long spatial wavelengths of a mountain surface, for example. Are we looking at the mountains, trees or grass? When characterizing the grass Ra or roughness average is used as in the calculations in Fig. 1. Ra takes a 2D profile then looks at the area bounded by that profile calculating a best-fit mean line divided by the length to give only a sense of how high these undulations are. The trouble with this is if we take all the peaks moving them to the right and the valleys moved to the left we have the same Ra value. The same is true if we flip the part over; we get the same Ra value. Ra alone, only provides general information. No specific information is provided. Beginning a data set with R signifies 2D data. Beginning a dataset with an S shows this to be 3D texture information. Sa is in a 3D aerial profile.

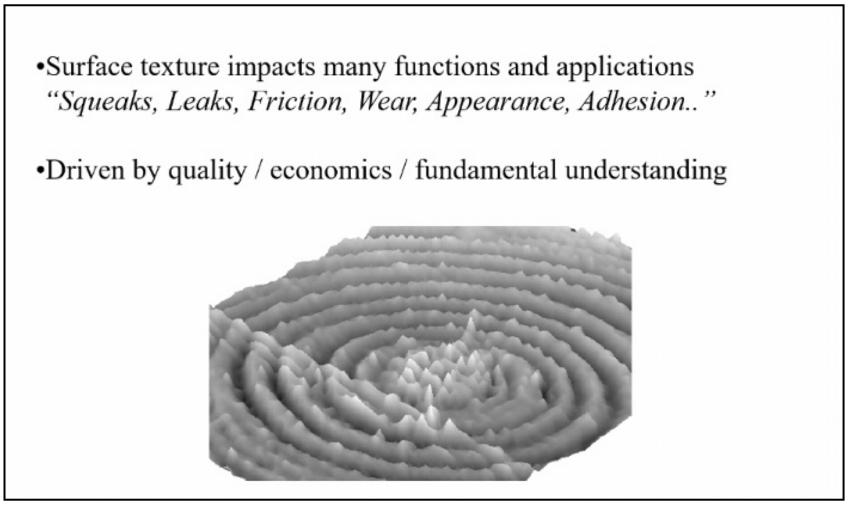


Figure 3. The criteria for imposing a surface texture inspection requirement.[1] (Artwork courtesy of Udemy Instructor, Donald Cohen.)

BACKGROUND

When discussing the surface finish of castings, it is necessary to understand the sometimes complicated and mostly misunderstood application of surface texture discipline (Fig. 3). Casting suppliers expect no quality issues after a shipment is delivered. It is the number one priority for castings to be at or above quality requirements. Casting surface finish inspection requirements can make this goal difficult to reach. Loosely written surface finish requirements are a "roll-of-the dice" because they can be tightly interpreted. It is uncommon to encounter a surface finish drawing note that was written by an expert in the subject of surface finish. The designer usually just grabs at a typical limit say 125 RMS or 63 Ra without specifying how it is to be inspected, with what instrument, at what instrument settings and in what specific location on the casting (Fig. 4). Those details are usually not identified. Does the designer know why they need a surface finish requirement? What is the functional need for a surface finish requirement? Is it airflow or mating part fit-up? Is it a cosmetic need for end-user or customer visual appearance? Or, is the surface condition determined by the previous supplier's finishing preference in which everyone became accustomed? It should be looked at like this: If the surface texture functional requirement does not include *Squeaks, Leaks, Friction, Wear, Appearance* or *Adhesion* then perhaps there is no need for a surface texture requirement. It has been learned in airfoil casting that engineers/designers do understand the intricacies of surface texture and surface inspection. Airfoil/airflow designers also seek applied casting advice to combine with the data derived from analytical simulation tools such as ANSYS simulation software. Without such tools, a designer and metalcaster just loosely say "it's 125," for example. A better approach would be to establish a clear reason for the requirement and the method to verify it. Designers need to be aware that RMS and Ra are different. For a normally distributed texture amplitude (i.e., bell curve distribution) RMS is about 11% higher than Ra. Also, it is necessary to understand skidded vs. un-skidded profilometer styli which provide different surface assessments. Surface finish is a measurement of the overall texture of a surface, consisting of three key elements *lay, waviness,* and *roughness*.[1,2] Lay refers to the dominant pattern on the surface, produced by the manufacturing process itself. Waviness measures the amplitude of the longer spatial wavelength components of the texture (e.g., "mountains").

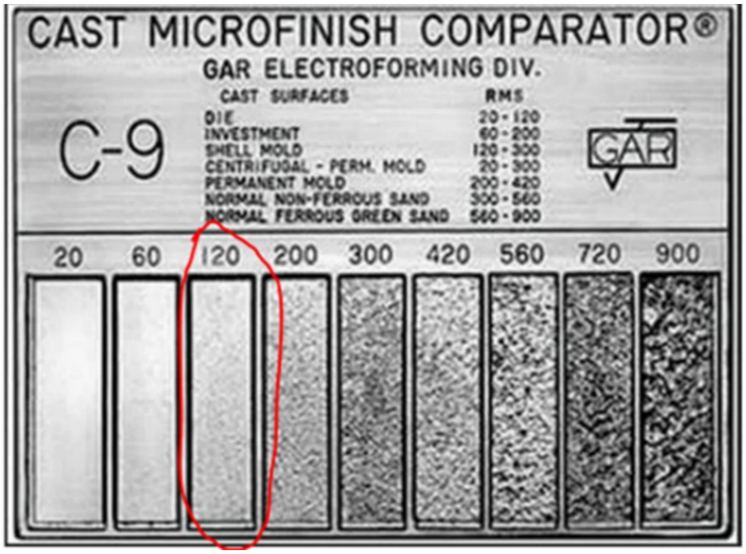


Figure 4. A cast microfinish comparator recommended for the evaluation of as-cast surfaces by the comparison method. A 120 RMS is typical for the investment casting process in this discussion.[3] (Artwork courtesy of Impro Aerotek, USA.)

Roughness measures the amplitude of the shorter spatial wavelength components of the texture (e.g., "the grass).[1,4] Surface finish can be measured by direct measurement, non-contact, comparison, or in-process methods. Direct measurement is usually done in a "contact" manner with a stylus dragged across a specific location and at a certain length and specific pressure to measure surface finish getting an average and general profile of its roughness.[5,6,7]

Non-contact methods replace this stylus with optical sensors and lights or ultrasonic pulses which are very good today.[8] Surface texture experts have been involved in developing these machines making them a sound new technology for metalcasters to utilize. It is suggested to understand these machines including their technology and capabilities as they relate to the actual need of an as-cast surface, before simply applying a specification in a drawing note. Consult with surface texture experts and the manufacturer in order to craft a surface texture drawing requirement. It should be considered that these instruments may be expensive and not currently available in every foundry.

It will not be acceptable to specify for example, "comparison method" or "profilometer method" and then expect a non-contact/digital method to provide a meaningful set of data. Good-bad/accept-reject requirements are not accepted. The comparison method involves creating a surface finish sample using the same equipment or process that produced the casting. These techniques, which typically include simple visual or tactile verifications, can be useful when roughness parameters need only be approximate. However, these methods are not ideal for verifying fine details or tight tolerances. In-process methods determine surface finish with techniques such as: machine vision, magnetic inductance, and ultrasonic methods. When it comes to taking surface roughness measurements there are three primary types: *profile, area* and *microscopic* techniques. Profiling techniques take measurements of the part's surface with high-resolution scanning probes along a 2D line.[5] Area techniques, such as optical or ultrasonic, measure a specific locale over a 3D region.[9] Microscope techniques allow one to examine surface finish, in fine detail. These tools are limited by their small fields of view requiring multiple scans to establish average roughness conditions.

Achieving a proper surface finish does more than just make parts visually pleasing to customers. It also helps to ensure that the piece functions as intended.[2] Surface roughness can be measured in a variety of ways, but the techniques listed here are a general overview of what is practical and available. Surfaces roughness can vary based on the many manufacturing methods and secondary processes: i.e., sand casting, shell, core, grinding, blasting materials, blasting techniques, belting, etc.

ANSI/ASME B46.1-2002 Surface Texture (Surface Roughness, Waviness and Lay) defines parameters for specifying surface texture.[10] It is required to take at least five sample lengths with a mean value of the five readings across the lay of the surface which shall be 83% to 112% of nominal value. This is not a one-off good-bad assessment as much of the industry tries to impose. A customer shall not reject (or accept) a group of castings based on one good-bad surface texture measurement. There was a contentious surface finish inspection situation created, during one of the author's customer experiences, because no surface finish requirements were specified ahead of the purchase order. The size of the shipment and the implications of the fixed process which had been signed off by both the metalcaster and customer, led to a tenuous situation. The use of specification ANSI/ASME B46.1 resolved that customer situation. It requires that surface finish inspection elements be specified.[10] Also note that it is difficult to attain gage R+R quality data on an as-cast surface. It is "impossible" to correlate one reading in a random unknown area of one casting, then use that as "data" to reject a group of castings. Unfortunately, this is what customers attempt to do. It must be understood that different areas of the same casting may have different surface textures and that good casting drawings indicate ("zone-out") the area where surface testing will occur.

The following data comes from a collaborating casting company.[11] The experiences shared, on their website, are about surface finish and inspection. This page states: "every few years a profilometer inspection of an as-cast surface texture will find and reject some area of a part for being in excess of 125 RMS maximum drawing requirement." Does the part even need the requirement? Why is surface finish specified? Is the inspection technique defined on the drawing according to ANSI/ASME B46.1?[10] This collaborator (and the author agrees) argues against placing a surface texture requirement on a casting drawing unless the texture is important to the function of the part. These thoughts are supported in ANSI/ASME B46.1 Appendix B1 which shows that 60 to 200 RMS is the normal range of processing and an appropriate range of variation when specifying a surface texture requirement on an investment casting.[10] The occasional rejection of castings to a 125 RMS maximum requirement is also in part explained by ANSI/ASME B46.1 where it states that "Castings are characterized by the random distribution of non-directional deviations from the nominal surface."[10] The specification also states that "surface characteristics of castings should never be considered on the same basis as machined surfaces."
An inspection of an as-cast surface texture with a profilometer is in itself an inappropriate method for a casting. The inspection of as-cast surface texture should instead be performed by visual/tactile comparison to a standard (Fig. 4).

MANAGING REQUIREMENTS

How can surface finish requirements be managed and improved? This next example comes from an airflow improvement project pertaining to an industrial gas turbine six-vane segment airfoil casting. During that work, a collaborator worked together with an airfoil manufacturing group.[12] On the airfoil vane segment, the customer asked to improve the 63 RMS which was obtained in a standard vibratory unit, to 32 RMS which could not be attained with the same procedure. The collaborator suggested using the existing vibratory tubs, adjusting the media and the metering compound then to apply fixturing. The team methodically and scientifically made these changes. Trials were done in a data-based fashion with measurement according to ANSI/ASME B46.1. For example, this team did not use random one-off profilometer readings. As a result of their work, the finishes were attained and the resultant procedures were documented. The vane segment surface texture improvement project was a success gaining the company more business.

Specification ANSI/BSME B46.1 discusses the measurement of similar "lay" and similar "swirl" areas of castings.[10] It avoids allowing random areas to be inspected on as-cast surfaces due to these circumstances. (i.e., gate ground versus non-gate ground areas). Consider using averaging techniques or using a reference tool such as a visual/tactile comparator.

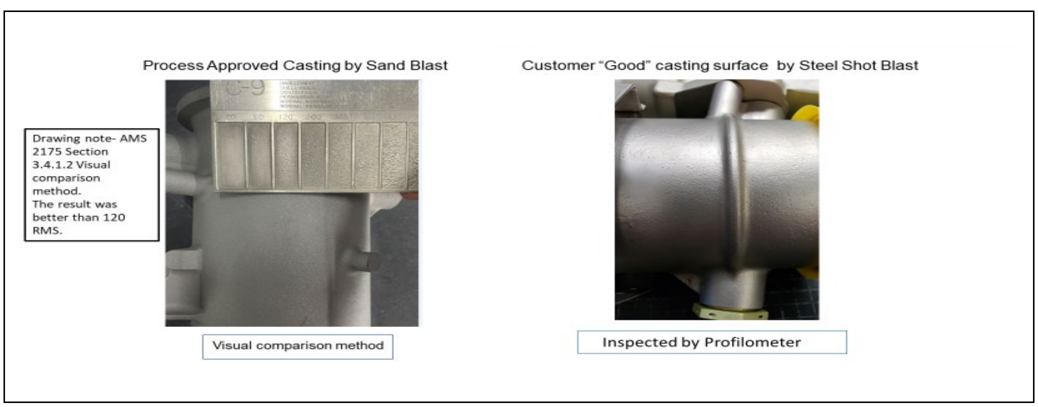


Figure 5. Examples of a shot-blasted vs. sand blasted casting with visual inspection vs. profilometer testing.[3] (Artwork courtesy of Impro Aerotek, USA.)

Those use the human eye or touch to consider a part's surface condition. Specification ANSI/ASME B46.1 considers part "lay" where casting drawings do not take that into consideration.[3,10] Roughness average, Ra, which is the average surface roughness differing from Rmax that measures the vertical distance of surface peaks and valleys. Examples of this are burrs and scratches not easily detected with the Ra surface finish chart.[2] Rz is the average maximum height profile of a surface.[13] Average values of the 5 largest differences between peaks and valleys across the surface entirety, is required for a final measurement. Ra is insensitive to some of the extremes.[13] Micrometers are a unit used for a rough low-grade measurements. For example, 12.7um or 500 microinch. Microinches provide the finest granularity measurement unit equating 0.8um to 32 microinches. Also, the 0.08um machine grade surface is created by centerless, cylindrical or surface grinding.

Shot blasted casting surfaces like the casting in Figure 5 (right) are created by round media which is usually a steel sphere that peens and polishes the surface. This causes the part's appearance to be somewhat shiny. Angular media cuts/opens the surface to attain a good surface for fluorescent penetrant inspection (FPI). Investment casters use angular fine-grit sandblast media as instructed in FPI process specification ASTM E1417.[14] Peening is prohibited prior to FPI, without pre-FPI etch as shown in E1417 which is also referenced in AMS 2175.[15] E1417 is a significant quality specification that covers many parts. It impacts all parts from hot section airfoils to fuel nozzles to bearing housings and structural castings. Switching to glass bead media is permissible by specification E1417 without pre-FPI etch.[14] This process, however, is to be controlled. The application pressure shall be between 20-50psi. Glass bead is a round media that can have the added effect of peening. In agreement with the customer, a casting supplier can switch to a glass bead product in order to provide a different surface appearance. That is one way to deal with surface appearance and still remain within the ASTM E1417 guidelines.

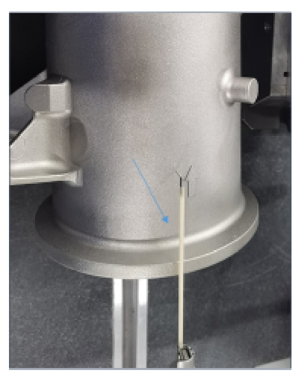
MATERIALS & EQUIPMENT

MATERIALS

A look at the materials involved in creating surface finish texture—Shot Blast is available as cast-iron spheres (approximately 0.05" in diameter) or as a cut-steel wire product. Shot is the least expensive blast media because it is useful for 150 cycles in a blast room or in a blast cabinet. There are no "fines" produced, using steel-shot. Also, it is noted that fines are difficult to handle. Fines create dirty casting surfaces which will not go through fluorescent penetrant inspection without extra cleaning. Sandblast or "grit" as sand is termed in ASTM 1417, cuts/opens the surface enough to assist FPI in attaining a true reading of part quality.[14] Next, is aluminum oxide that lasts 80-100 cycles and is not quite as durable as steel-shot. Sands, such as aluminum oxide and alumino-silicate materials break down producing "fines." Fines cause the need for recycling/sifting and the use of dust collection equipment. They must be replenished properly. Aluminum oxide is the most expensive media. Alumino-silicate sands fall, in the middle between steel-shot and aluminum oxide from a cost standpoint.

Profilometer is in Ra mm | Test location "next to the arrow"

Surface Roughness Conversion Chart					
Ra micro-meters	Ra micro inches	RMS	CLA	Rt	Cut-off Length in.
0.025	1	1.1	1	0.3	0.003
0.05	2	2.2	2	0.5	0.010
0.1	4	4.4	4	0.8	0.010
0.2	8	8.8	8	1.2	0.010
0.4	16	17.6	16	2.0	0.010
0.8	32	35.6	32	4.0	0.030
1.6	63	69.3	63	8.0	0.030
3.2	125	137.5	125	13.0	0.100
6.3	250	275	250	25.0	0.100
12.5	500	550	500	50.0	0.100
25	1000	1100	1000	100.0	0.300
50	2000	2200	2000	200.0	0.300



Ra = Roughness average= Arithmetic Average.
RMS = Root Mean Square.
CLA = Center Line average
Rt = Roughness total
Cut-Off Length = Length required for sample.

Figure 6. Different units of measure provide dissimilar values.[3] (Artwork courtesy of Impro Aerotek, USA.)

EQUIPMENT

Blast equipment manuals call out parameters for the different equipment types used. Mostly, the difference is in a suction cabinet or a pressure unit. The supplier will need to take sufficient downtime from production, to replenish new sand and remove fines. This is something to be noted during plant tours. Replenishing can be an untidy and time-consuming process. Because it is difficult, there have been occurrences of short-cutting this process resulting in fines remaining in the unit and gathering on the surface of parts rather than doing the surface finish work needed. Caution is urged when using shot due to the peening nature of this process. In the case of stress relief, peening is required.[16] However, for surface texture creation, peening is an unwanted by-product. Peening could mask metallurgical conditions on the surface of castings, for example.

Surface texture values are utilized in different units. These units are not interchangeable. They do not have the same values, yet they are oftentimes judged as being interchangeable by designers or inspectors. Figure 6. shows surface texture units/values comparatively. The location for testing on the surface of a casting is very important. It is appropriate to choose a specific location on the surface of a casting in which to record the necessary profilometer/comparator or non-contact readings. That location is to remain constant on all castings checked. Location is one of the agreements between casting purchaser and producer that must occur at or before contract review. In Figure 6, notice on the right, the different mathematical definitions for units of surface texture. RMS is root-mean-square. Ra is roughness average like arithmetic average and CLA-center line average, for example. These units do not provide the same values. This must be understood before being put to work on a drawing note or in a casting specification.

ADDITIVE MANUFACTURING

Additive manufacturing (AM) and surface finish come together, as is the case with any manufacturing process. Where the designer is concerned about the impact of surface finish to the part's integrity, structure, fatigue, cooling, fluid/airflow and appearance. Problems in additive manufacturing occur relative to surface texture, surface finish and inspection. In additive manufacturing, producers may experience surfaces which now have different textures compared to surfaces which were previously as-cast. With AM, a surface may have a higher peak or a deeper valley than in the normal pre-additive state. This occurrence does not automatically mean surfaces are not good. Surfaces may appear differently, but they may not have a structural requirement. Perhaps there is just a cosmetic expectation to look the same as-cast. Utilize structural assessment software and tools available when designing and specifying surface finish, in an additive manufacturing situation. For example, this is how turbine engine OEMs are able to attain the surface finish/texture needed, in castings. Experiencing structural analysis as it relates to casting surfaces, in a turbine engine setting, is very insightful to this topic. The use of structural assessment tools (i.e., ANSY, and others) along with applied casting advice is the proper way to know, for certain what structure is possible to attain in a particular surface texture. It is equally important to understand the manufacturing methods and costs associated with attaining that surface texture. In an AM conversion, it is important to cover the same level of design/engineering detail as is done in a conventional casting conversion. This level of detail is needed, upfront, in order to experience a smooth transition to an additively manufactured component. When writing the surface texture drawing note/casting specification it is best to follow the guidelines in ANSI/ASTM B46.1 and come to agreement, about surface texture/finish before manufacturing begins.

CONCLUSIONS

Three basic points to take away from this work are:

1. Purposeful development of a data-based surface texture/finish design requirement is needed.
2. Utilize ANSI/ASME B46.1 to write the surface texture/finish drawing requirement/casting specification.
3. Collaborative work between the casting purchaser and metalcaster in developing the final surface texture/finish drawing requirement in vital to project success.

ACKNOWLEDGEMENTS

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