White Paper

Surface Finish: An Important Characteristic in Fluid System Components

The surface finish of process vessels, piping and related components can be a critical factor in their performance, maintenance costs, and service life. This characteristic may also be influenced by industry standards, which manufacturers and processors must satisfy.

It is well known that the surface finish of vessels, piping and related components can have profound effects on how well a fluid system performs. Typically, surface roughness is a critical parameter in the assessment of surface finish on fluid system components. This parameter can affect fluid flow resistance (friction), adsorption/desorption, bacteria growth, the build-up of chemicals from a process fluid, corrosion formation, pressure drop, etc. Ultimately, surface finish can affect service life and maintenance costs.

Standards, Specifications and Certifications

Increasingly stringent specifications are creating greater demand for improved surface finish on most metal components that are part of process equipment. In particular higher purity requirements in the pharmaceutical and biotechnology industries require surfaces in contact with the product to have finishes that meet the ASME-BPE-2009 Standard. This standard provides specifications for the design, manufacture and acceptance of vessels, piping and related components for application in equipment used by the bioprocessing, pharmaceutical, and personal care product industries. This standard includes aspects related to sterility and cleanability, materials, dimensions and tolerances, surface finish, material joining, and seals. Meeting the surface finish requirements of this standard is rapidly becoming a universal necessity in the manufacture of other fluid process equipment. As a result, suppliers of equipment and components are often required to quantify the surface roughness of their finished products.

Some additional standards and specifications that directly or indirectly affect surface finish requirements include:

- ASME B46.1-2002 – Surface Roughness, Waviness, and Lay
- ISO 4287 and 4288 – Geometrical Product Specifications (GPS)
- DIN ISO 1302, DIN 4768 – Comparison of Roughness Values
- ASME Y14.36M – Surface Texture Symbols
- ASME B16.5 – Pipe Flange Face Roughness
- DIN 7079 Standard for Fused-Glass Sight Glasses in Metal Frames

Manufacturers' certifications are one way of assuring customers that an end product meets their requirements. Generally, these certifications involve performance or safety features that go beyond characteristics such as surface finish. However, surface finish often has a significant influence on performance. As an end product example, L.J. Star Metaglas® sight glasses conform to USP Class VI and are BPE compliant.

Surface Finish Measurements

All manufactured components have some form of surface texture, which has elements of lay (the machining or forming pattern), surface roughness, and waviness. In addition, inherent material properties may contribute to surface porosity, inclusions, and residual elements. The parameters of texture are vertical amplitude variations, horizontal spacing variations, or some hybrid combination of these. Surface roughness is an expression of finely spaced vertical surface irregularities. Waviness refers to irregularities with spacing greater than surface roughness.

A typical contact method of measuring roughness is to use a profilometer, which involves dragging a stylus across the surface being measured. Non-contact methods, most of which are more involved and costly, include interferometry, confocal microscopy, focus variation, structured light, electrical capacitance, electron microscopy, and photogrammetry [1]. Generally, measurements (samples) are taken in several directions. Depending on conventions in different countries, industries, applications, etc. the units used to express surface finish or roughness will vary. Likewise, various industry standards are used to specify the degree of roughness allowed or recommended in different applications. These standards include those published by ANSI, ASME, SAE, ISO, and other organizations.

Commonly used expressions of finish include:

- **Standard grit reference** – refers to the grit of a surface finishing medium or method, which does not provide a consistent measure of roughness, since results depend on a part's material, finishing method, lubricant used (if any), and applied work pressure.
- **N** – New ISO (Grade) Scale numbers. These are used on manufacturing drawings that specify surface finish in terms of an ISO standard. Each roughness grade number can be correlated to a specific Ra number that is expressed in microns.
- **Ra** – Roughness average, most commonly expressed in micrometers (microns). This is the most universally recognized and used international standard of roughness measurements. It is the arithmetic mean of the absolute departures of a roughness profile from the mean line of the measurement. Ra may also be expressed in microinches.
- **CLA** – Center Line Average in micro-inches. This is a conversion using Ra(µm) × 39.37.
- **RMS** – Root Mean Square in micro-meters or micro-inches; i.e., the average of peaks and valleys of a material's surface profile as calculated from a number (n) of measurements (x) along the sampling length:

  $$x_{\mathrm{rms}} = \sqrt{\frac{1}{n}\left(x_1^2 + x_2^2 + \cdots + x_{\mathrm{n}}^2\right)}$$

- **Rp** – Maximum profile peak height.
- **RSm** – The mean spacing between profile peaks on the mean line, measured along the sampling length.
- **Rt** – The total height of a roughness profile, typically expressed in microns, is the maximum peak-to-valley height along the assessment length.

Some expressions of roughness can be converted to another form in a straightforward manner, such as converting a micrometer expression into microinches. For example,

$$\text{CLA (microinches)} = \text{Ra}(\mu\text{m}) \times 39.37\text{(inches/meter)}$$

Other conversions use factors that have been establish as generally acceptable over time, but some of those may be a bit controversial and a range of factor values is often given. In the case of an RMS conversion from CLA, acceptable conversion factors lie in the range of 1.1 to 1.7. A factor of 1.1 is often used, i.e., RMS(µin.) = CLA(µin.) × 1.1. **Table 1** lists conversions for some commonly used roughness expressions and values.

Table 1. Conversion values for equivalent expressions of roughness.

Grit No.	ISO No.	Ra (µm)	Ra (µin.)	CLA (µin.)	RMS (µin.)[1]	Rt (µm)[2]
—	N12	50	2000	2000	2200	200
—	N11	25	1000	1000	1100	100
—	N10	12.5	500	500	550	50
60	N9	6.30	250	250	275	25
—	N8	3.20	125	125	137.5	13
80	—	1.80	71	71	78	9.0
—	N7	1.60	63	63	64.3	8.0
120	—	1.32	52	52	58	6.6
150	—	1.06	42	42	46	5.3
—	N6	0.80	32	32	32.5	4.0
180	—	0.76	30	30	33	3.8
220	—	0.48	19	19	21	2.4
—	N5	0.40	16	15	17.6	2.0
240	—	0.38	15	12	17	1.9
320	—	0.30	12	9	14	1.5
400	—	0.23	9	8	10	1.3
—	N4	0.20	8	4	8.8	1.2
500	N3	0.10	4	2	4.4	0.8
—	N2	0.05	2	1	2.2	0.5
—	N1	0.025	1	1	1.1	0.3

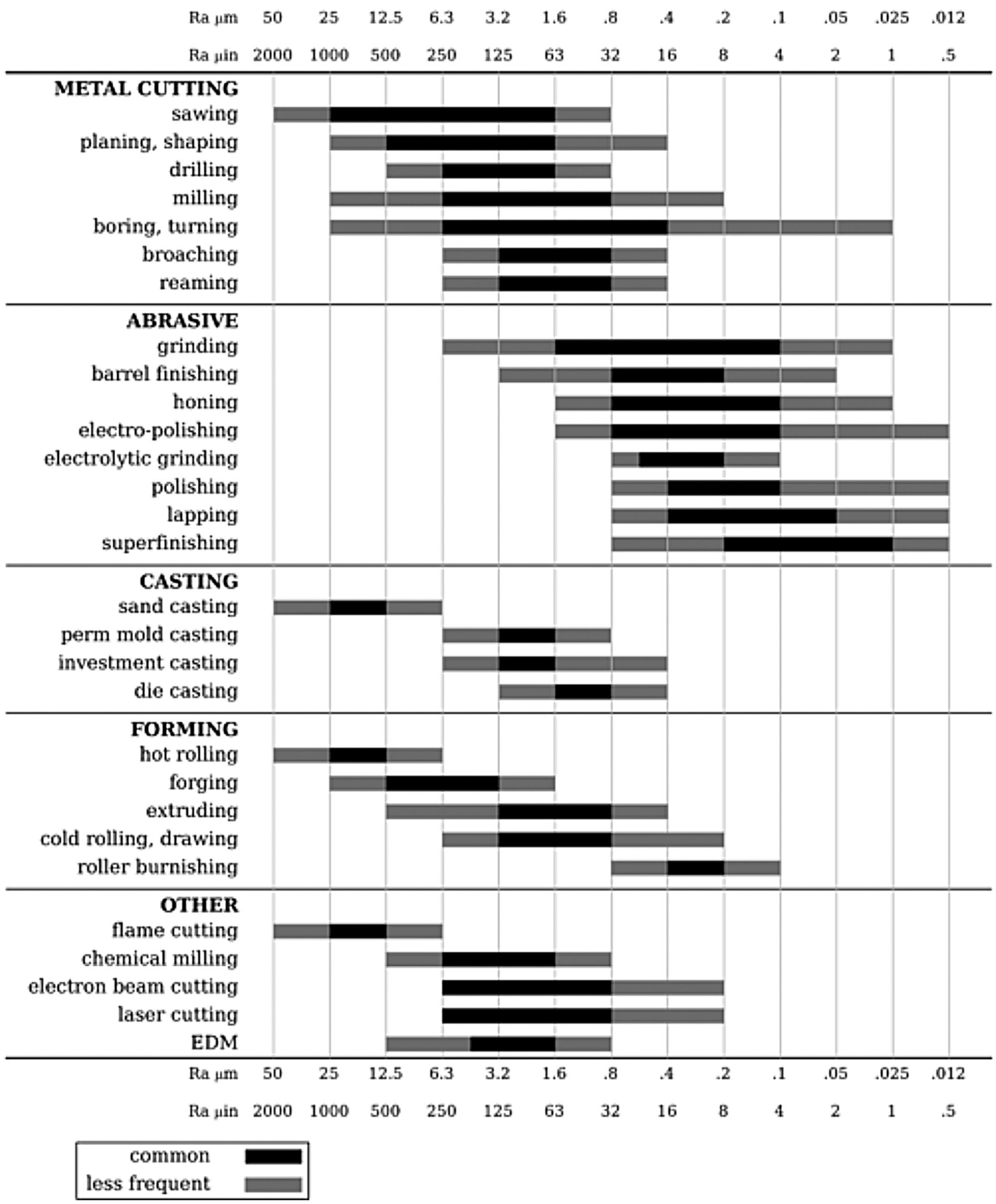
Notes:

1. A factor of 1.1 × CLA is used throughout this table to calculate RMS(µin.)
2. Typically, for values of Ra from 50µm to 3.2µm, the conversion factor for Rt (µm) is 4. As surface roughness decreases from 3.2µm, the conversion factor increases, reaching 12 at 0.025µm. This is reflected in the table above.

Manufacturing Processes

Primary manufacturing processes govern the initial surface of components and their roughness values [2]. In the case of metallic components, additional finishing processes may be used to reduce the degree of roughness to fit a specific application. **Table 2** lists typical Ra values for various metal finishing methods. In the case of fluid system components, the motivation to reduce surface roughness could be to reduce flow resistance and pressure drop, improve sealing, reduce build-up of process chemicals on the metal surface, improve corrosion resistance to increase life, etc. In sight glasses, for example, the surface roughness of both the glass and the metal mounting ring are critical for achieving a good seal in the installation.

Table 2. Typical range of Ra surface roughness values in various metal forming operations.



Source: Wikipedia http://en.wikipedia.org/wiki/Surface_finish [1]

Various types of polishing operations are commonly used to reduce the surface roughness of metals used in fluid vessels, piping and related components. These fall into two categories: mechanical polishing and electropolishing. As the name implies, mechanical polishing involves the application of physical force on abrasive media to remove surface irregularities. While it's theoretically possible to achieve low roughness values with certain mechanical polishing techniques, the time and cost involved usually makes this impractical. Generally, mechanical polishing is used when moderate roughness values are acceptable, which means numerous surface scratches and other irregularities remain. These can cause many of the problems mentioned in the first paragraph of this section. For example, these irregularities can cause areas of differing electrical potential due to surface stresses, which become sites where corrosion begins.

Electropolishing is an electrolytic process (the reverse of plating) combining electric current and chemicals to remove metal without smearing or folding. The peaks of burr, folds, inclusion and other anomalies of a metal surface are dissolved more quickly than valleys as a result of the greater concentration of current over the protuberances. This electrochemical action produces a smoothing and rounding of the surface profile, resulting in irregularities as small as 0.01 micrometer (0.04 micro-inch). It prevents or reduces most of the problems associated with rougher metal surfaces. The inherent benefits of electropolishing subsequent to mechanical polishing include:

- Removal of surface occlusions
- Removal of inclusions and entrapped contaminants such as lubricants and grit particles
- Cleaner surface of the "wet contact" areas
- Reduced surface area/chemical reactivity for less absorption and adsorption
- Less contamination and build-up of process chemicals on a surface
- Superior surfaces for cleaning and sterilization
- Elimination of localized corrosive cells (galvanic differences) remaining after mechanical polishing
- Resultant passivated surfaces enhance corrosion resistance
- High luster reflective appearance
- Reduced surface friction

References

1. Wikipedia, http://en.wikipedia.org/wiki/Surface_finish
2. Degarmo, E. Paul; Black, J T.; Kohser, Ronald A. (2003), Materials and Processes in Manufacturing (9th ed.), Wiley, ISBN 0-471-65653-4.

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