How To Define Silicone or Plastic Finishes For New Products (Whitepaper)

Introduction

Almost all materials can have a finish applied to them, and plastics and silicone are no different. The finish added to the plastic or silicone depends on several things, including the type of polymer used and its physical and chemical properties, the application the part or component is used in, and the type of fabrication process and its parameters.

The plastic used in an automobile dashboard is very different to the case of Apple Airpod earbuds, for instance, but they are both textured polymers. The same can be said for some smooth silicone medical tubing and a grippy silicone phone case. In fact, adding textures or finishes to everyday plastics or silicone products is an extremely common requirement for manufacturers as the majority will be seen or used by consumers. Therefore, the addition of finishes can have both an aesthetic *and* functional purpose.

In this whitepaper, we have collected a number of resources to help you understand how to define the finishes of new plastic and silicone products, with a special focus on plastic and silicone injection molding.

You may like to skip ahead to see example images of some of the typical finishes that can be added to plastics, some of the key plastic texture standards products may follow, and example images of mold textures for silicone products, too.

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Plastic Parts & Products

Deciding which plastic material and finish to use

For a plastic injection molding manufacturer that offers custom-made products, the first goal is to work in collaboration with the customer to determine the importance of surface finish for the exterior appearance, as well as the performance of the injection molded product, or to be specific, is the final product an eye-catching piece or simply a functional one? Your answer to this question determines the choice of material and the option of surface finish, based on which the plastic injection molding process is set, and the secondary finishing operations are accordingly required [2].

What is of special importance is the type of the material, e.g., the higher the melt temperature of the products made from reinforced crystalline resins, the more glossy and less rough the surface is, thus creating a smoother effect. However, when being plastic injection molded, a higher mold temperature can improve the glossiness and reduce the roughness of the reinforced amorphous resins [2].

Aesthetics or functionality?

The finish chosen is a big decision for manufacturers. If your product is machined or molded it may have machine marks or flow lines that could be hidden by the right finish, so this is an aesthetic decision. On the other hand, a texture in the right place can improve the grip or plastic adhesion of a product, so that's a functional decision.

In surfacing finishing, a balance needs to be achieved between aesthetics and functionality, because the surface finish is able to affect not only the friction coefficient but also the resistance to wear and tear; if these are considered to be important characteristics for the product performance, the design team is then required to choose the material and process that helps create a well-matched finish effect[2].

It is of critical importance to decide the surface finish type as early as the design stage because it has a great influence on your selection of material and tooling, as well as your choice of the finishing process. The surface finish of a product is limited by the textures on the tool steel [when using plastic injection molding to fabricate parts or products]. From time to time, imperfections, such as sink marks, on a surface can be covered by a rougher texture pattern. In addition, the draft required on a molded part can also be affected by the surface finish – if the draft is not appropriately designed, the surface finish could probably be destroyed during the ejection process [2].

Before making your final decision on the surface finish type for a plastic injection molded product, you should first have a clear idea in mind of what type of mold you need based on your production volume, as well as the type of material that your mold is going to be made of. Usually, a steel mold is of higher hardness than an aluminum one, thus able to offer more surface finish options, because the steel material possesses the benefit of being able to be polished for a surface finish that is smoother than other materials, which is also helpful for such secondary finishing operations as painting aimed to enhance your final molded products [2].

Two considerations for finishes: Polishing and texturing

When it comes to plastic part design and surface finish, there are two main considerations to keep in mind [regardless of whether you are adding a finish for aesthetic or functional purposes] – polishing and texturing [4].

- **Polishing**: Polishing is a manual process that removes texture, machining marks, etc. on the mold surface and provides a uniform finish. Polishing can be very time consuming, especially if there are deep ribs in the mold.
- **Texturing:** There are several ways to texture a mold surface such as bead blasting, EDM (electrical discharge machining), or etching. A surface with a heavy texture will require increased draft angles torelease from the mold.

Your production process will dictate the type of finish available and how polishing or texturing can be used.

Three plastic production processes and their finishes

Most plastic parts are produced using 3D printing, CNC machining, or plastic injection molding, with the latter, molding, being used for most mass productions as it's most suited to producing plastic parts or products in large numbers with minimal wasted material.

Each of these production processes provides different finishes after polishing or texturing is used.

3D printing

In this additive method of fabricating plastic parts, 3D printing typically takes a three-dimensional digital model and recreates a physical version of it by melting polymer from a spool and adding very thin layers on top of each other successively until a final three-dimension model is produced. 3D printing is often used for prototypes or very small production runs. Completed parts may have seams and other imperfections that will need some kind of finish to remove.
Read more about 3D printing prototyping here.

CNC Machining

CNC machining uses a high-speed, computer-controlled, precision machine to remove metal or plastic from a blank, or block of metal or plastic, to create a part. It literally carves or cuts away layers of plastic until the desired shape has been achieved (subtractive

manufacturing). Again, this is ideal for prototypes and small production runs. Since the spinning tool cuts away plastic at speed the initial texture can be quite 'rough and ready' and so some kind of finishing will be required before use.
Read more about CNC prototyping here.

There are several different surface finish options [that can be used with 3D printed or CNC machined plastic parts][1]:

- **Plating:** A plastic part can be covered with a coat of metal using either an electrical or chemical process, but one must first treat the part with conductive paint for the plating to work.
- **Sanding:** Sandpaper can remove manufacturing imperfections, and the part smoothed out with an even surface.
- **Polishing:** After sanding, applying a plastic polish will give the part a glossy surface finish.
- **Bead blasting:** Like sanding, bead blasting will smooth out the surface of a part and give it a matte finish.
- **Vibration & tumbling:** Vibrating or tumbling the part in a container with ground-up material such as ceramic or a synthetic medium will polish it with repeated impacts.
- **Vapor smoothing & solvent dripping:** Solvent vapors or a bath can melt the part's surface, producing a shiny finish. It will also fill pores and seal the surface of the part. However, this process doesn't apply to all plastics, and its use can harm the part if not carefully monitored.
- **Epoxy coating:** Epoxy will also seal up a part and costs less as a tech usually applies it by hand. However, it may slightly change the part's dimensions, and users should carefully monitor its application.
- **Painting & dyeing:** One may also paint plastic parts for an aesthetic appearance or immerse it in a dye bath.
- **Re-machining:** Specific to CNC machining. The part is machined again, but this time with a smaller tool. This will reduce the machine marks and make the texture smoother, although they may still be visible.

Plastic Injection Molding

Unlike 3D printing and CNC machining which generally cater for low volumes and can be somewhat limited in terms of finish, plastic injection molding is the best choice for high volume production of plastic parts or products and, due to the nature of the mold, can provide numerous finishes.

Conventional production injection mold tools are constructed from hardened tool steel and can take weeks if not months to complete, depending upon the size and complexity of the part to be molded. They can also produce more than one part at a time with multiple cavities such as screw tops or other smaller parts. The liquid polymer is injected into the mold where it forms the desired shape, hardens, and is then ejected. A production mold could potentially handle up to 1m 'shots' until it needs to be renewed or replaced.

It usually takes months to fabricate and polish a new hard steel production mold due to their complexity, and one element is that the finish of the part/product being molded is often built into the steel unlike finishing on CNC machined or 3D printed parts which are often done after the part has been fabricated.
Learn more about plastic injection molding and the difference between rapid prototype tooling and hard steel production tooling here.

Injection mold finish types

In the following section, we share numerous examples of plastic injection mold finish types.

Available surface finish types include:

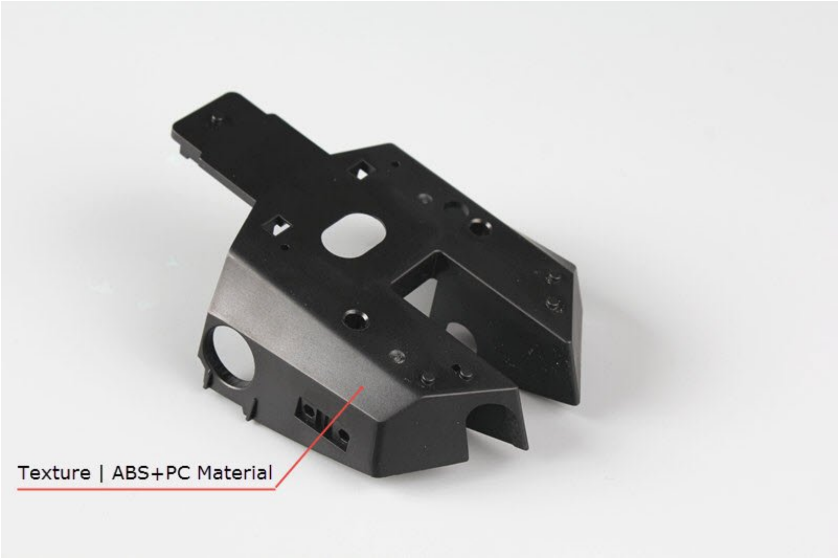
- Geometric shapes/patterns
- Grains, e.g., the leather texture
- Secondary finishes, e.g., paintings, print, etc.
- Etching
- Sandblast
- Glossy, matte, or satin finishes
- Mirror polishing or lens finishes

Below, you'll find some standard mold finish call-outs (**priced low-to-high**). While these standard SPI (The Society of Plastics Industry) call-outs are very common, a wide variety of textures are available. Some textures that can be applied include [4]:

1. Natural\Exotic
2. Micro Surface Finishes
3. Multi-Gloss Patterns
4. Graphics
5. Leather Grains/Hides
6. Woodgrain, Slate and Cobblestone
7. Geometric and Linens
8. Images or Logos incorporated into the pattern

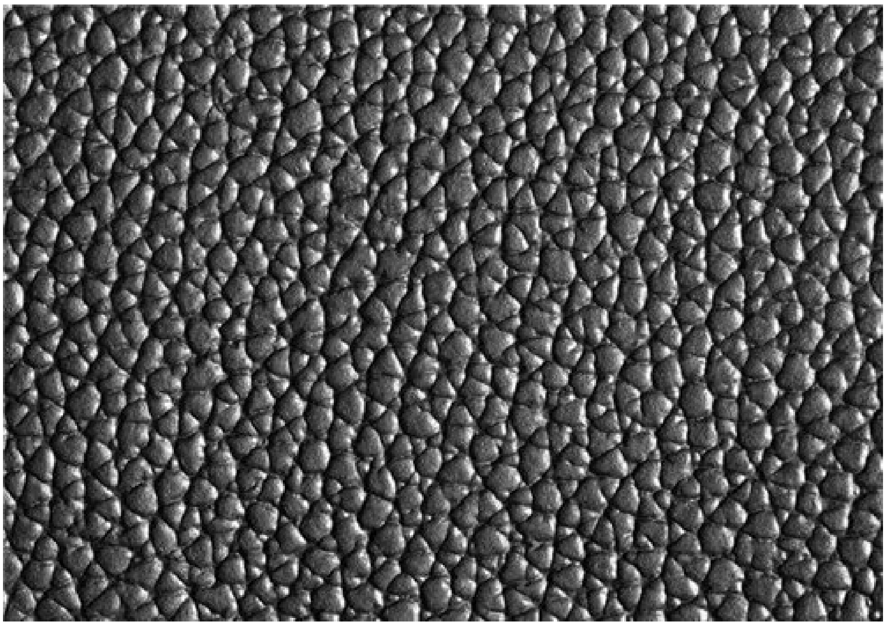
Textures in molded parts (Photos)

Here are some visual examples for the texture examples of actual plastic injection parts [9].

	SPI B1
	VDI Ref 27
	YS Texture 6291

According to the similarity of visual effect, there are 3 texture patterns [9].

	**Sand-pattern:** Fast and low cost
	**Satin-pattern:** Fast and durable

	**Leather-pattern:** Durable but difficult to fix

Surface Finish Standards For Injection Molding [2]

When you fabricate your injection mold tooling you have a choice of different texture standards for the finish from several different organizations. You can see them as follows:

1. **The Society of Plastics Industry (SPI)** (See Appendix A)

The Society of Plastics Industry (SPI) standardized surface finishes on injection molding tools. The process used to achieve the finish determines the following grades [1]:

- **Grade A - Diamond Buffing**: Diamond buffing paste has a very fine grain, so finishes are generally very glossy and product surfaces remain flat. Grade A finishes are considered the highest standard.
- **Grade B - Sandpaper**: This semi-gloss finish is applied using sanding grit and is ideal for hiding visible machining marks. The sandpaper grit number provides surface finish control — 600 for the finest finish, 400 for mid-range, and 320 for the most textured finish.
- **Grade C - Grit Stone**: Grit sanding stones generally follow the grit number and finish textures as sandpaper. However, grit stones cut fairly aggressively, which creates a rougher texture compared to B grades.
- **Grade D - Pressure Blasting**: Pressure blasting plastic surfaces with abrasives — typically sand or glass beads — results in non-directional patterns and dull or flat finishes.

Within each grade there are different levels of surface finish, which determines the degree of plastic surface texture. Generally, levels are sequentially numbered within the grades, with 1 being the least amount of texture and higher numbers correlating with more texture. For example, a sandpapered plastic surface finish categorized as a "B1" is semi-gloss and lightly textured; a "B3" is still semi-gloss but has more visual and tactile texture [2].

Injection molding finishing is an added cost — the higher the grade and finish level, the higher the bottom line. Since it can be a considerable investment, it's important to have an experienced custom injection molder weigh in on the appropriate injection molding surface finish and the most cost-effective tool classification [2].

SPI surface finish chart for roughness technology [3]

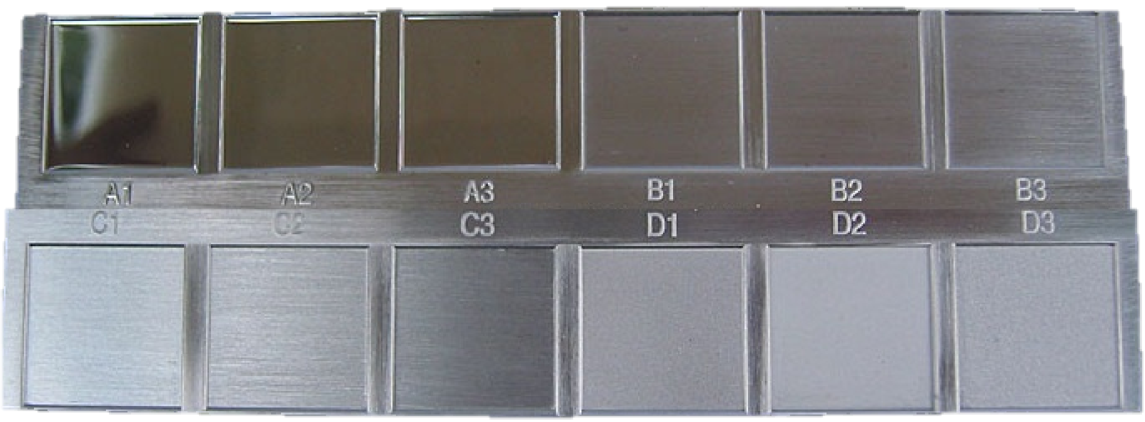
- SPI a1 is comparable to RA.0-1 made by #3 diamond buff
- SPI a2 is slightly finer than a1 and RA.1-2 made by #6 diamond buff
- SPI a3 has more imperfections than a2 and RA.2-3 made by #15 diamond buff

- SPI b1 is finer than a3 and RA.2-3 made by 600 grit
- SPI b2 is slightly finer than b1 and RA.4-5 made by 400 grit
- SPI b3 is comparable to RA.9-10 made by 320 grit

- SPI c1 is finer than b3 and RA.10-12 made by 600 stone
- SPI c2 is slightly finer than c1 and RA.25-28 made by 400 stone
- SPI c3 is comparable to RA.38-42 made by 320 stone

- SPI d1 is finer than c3 and RA.10-12 made by #11 glass bead sandblasting
- SPI d2 is comparable to RA.26-32 made by 240 aluminum oxide sandblasting
- SPI d3 is a little more coarse than d2 and RA.190-230 made by #24 aluminum oxide sandblasting

The picture below shows a variety of SPI finishes [4]



2. VDI Surface Finish or VDI 3400 texture (See Appendix B)

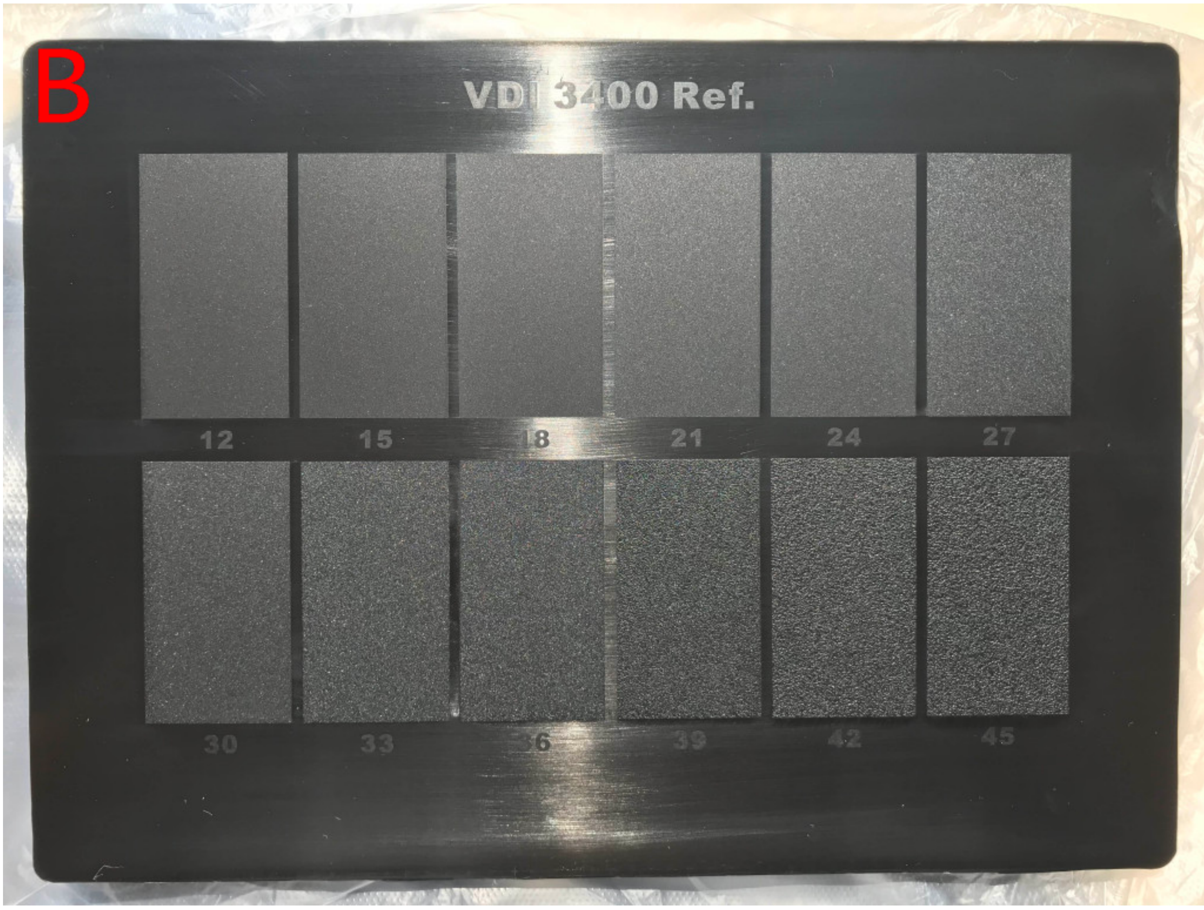
Several companies may utilize the VDI **3400** standard. **VDI 3400** refers to a **texture standard** set by Verein Deutscher Ingenieure (VDI), the Society of German Engineers. It is mainly processed by Electrical Discharge Machining (EDM) when mold machining, but could be also done by regular texturing method [6].

The complete VDI 3400 texture covers 12 values:

- VDI 12, VDI 15, VDI 18, VDI 21, VDI 24, VDI 27.
- VDI 30, VDI 33, VDI 36, VDI 39, VDI 42, VD I45.

Although the **standard of VDI 3400 texture** is set by the society of German Engineers, it is nowadays widely used worldwide among tool makers including north America, Europe and Asia [6].

The picture below shows a variety of VDI 300 finishes [7]

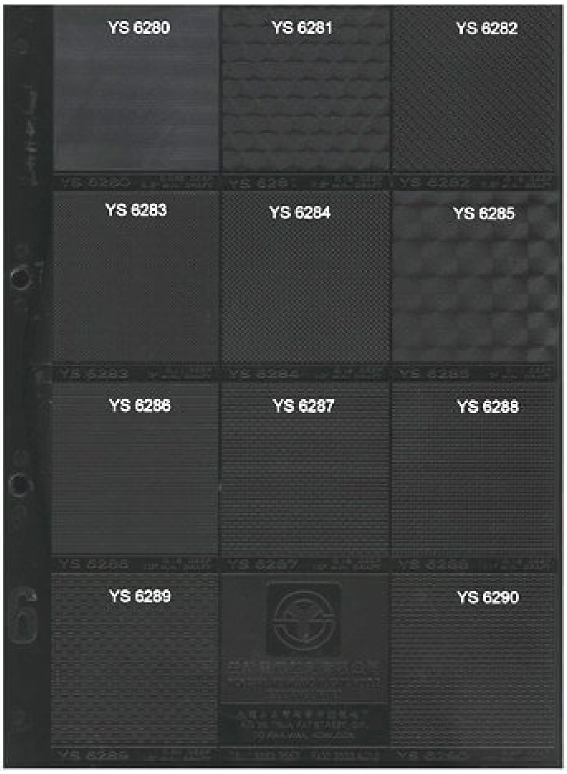


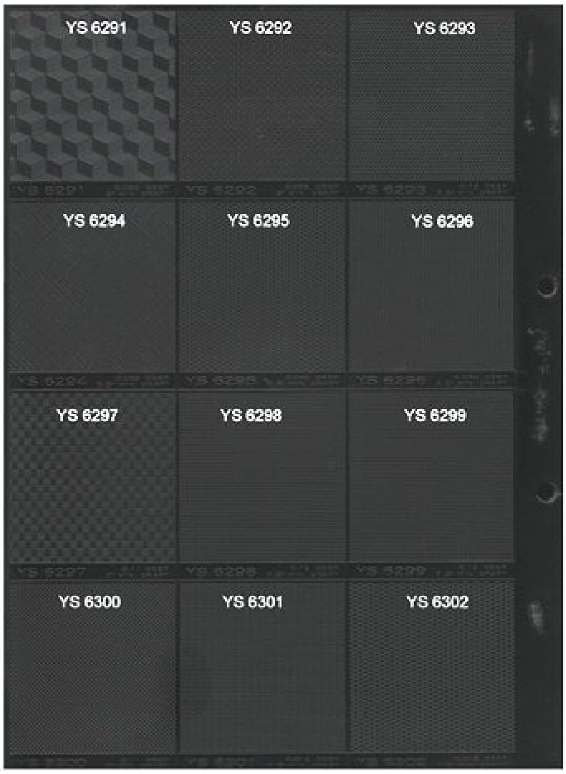
3. Yick Sang (YS) Texture Standards (See Appendix C)

Comparing with Mold Tech or VDI 3400 texture books, Yick Sang Texture Catalogue (YS Texture Catalogue) is the most comprehensive texture catalogue on the market. It covers 240 texture plaques ranging from plastic simple textures to complex ones such as wood textures, leather textures, flower textures and more [8].

Yick Sang Texture Catalogue (YS Texture Catalogue) is a powerful tool for industrial designers, tool engineers and product managers to decide or specify surface finishes for plastic products with their customers [8].

The picture below shows a variety of VDI 300 finishes [8]





Sources referred to in the plastic section:

1. https://www.plethora.com/insights/surface-finishes-for-plastic-pt
2. https://www.ecomolding.com/surface-finish/
3. https://www.spifinish.com/technology
4. https://rexplastics.com/product-development/fundamentals-plastic-part-design-part-6-ejection-surface-finish
5. https://upmold.com/resource/vdi-3400-surface-finish/
6. https://www.plastopialtd.com/vdi-3400-texture/
7. http://www.vdi3400.com/
8. https://www.plastopialtd.com/ys-catalogue/
9. https://www.plastopialtd.com/texture/

LSR Silicone Parts & Products

Introducing Silicone and its Benefits

Silicone and **rubber** are both elastomers. Silicone [or LSR] is a synthetic rubber produced from the chemical element silicon, with properties that organic rubbers just cannot match. Silicone rubber is an incredible compound with outstanding performance in lots of different areas. This makes it a very versatile material and the reason we use silicone rubber for products in almost every industry [4]. The picture below shows one of the common manufacturing processes of silicone products, for example phone soft cases.

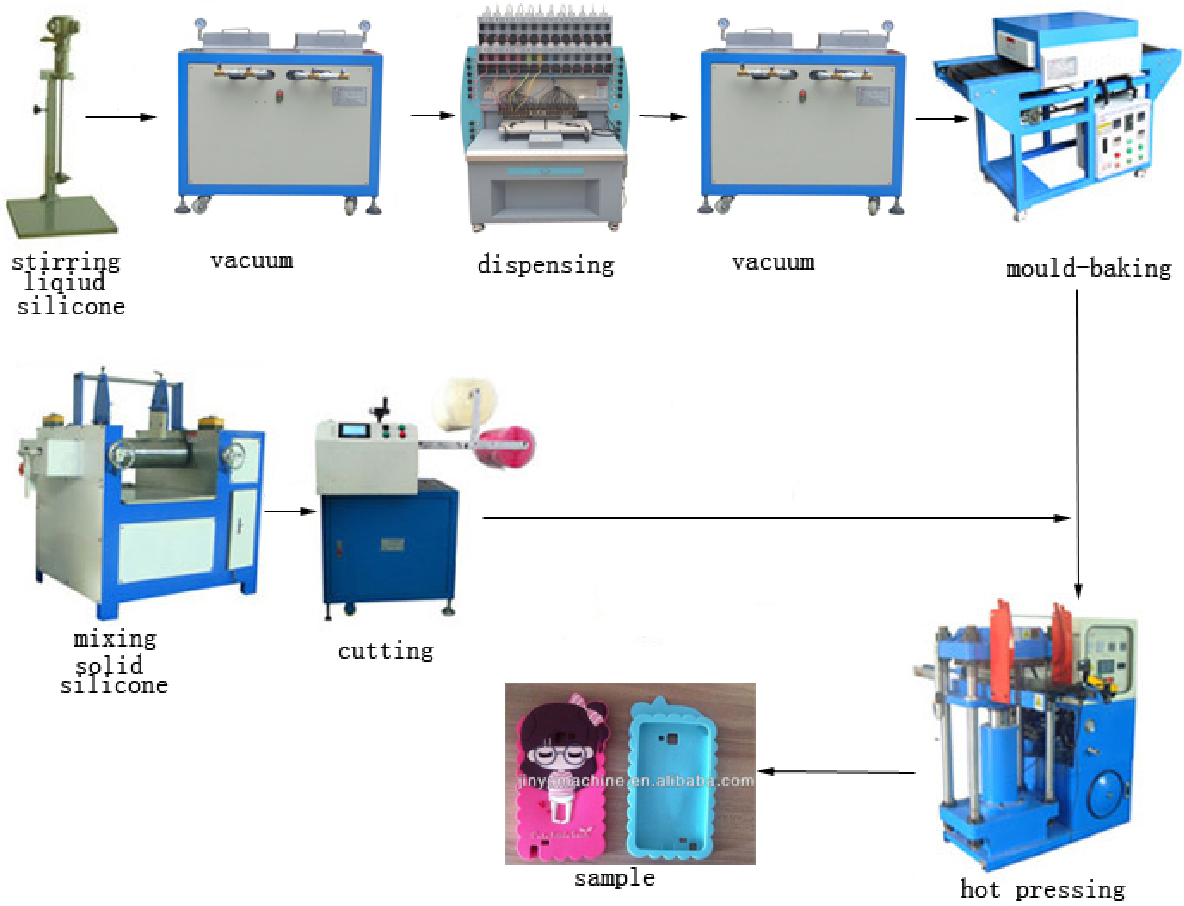


Image
Source: http://nealjy.blogspot.com/2018/03/mobile-phone-plastic-cover-making.html?m=0

Liquid Silicone Rubber has a long and proven history of use with medical devices and can provide many benefits, from flexibility to cushioning. However, silicones can present challenges due to an inherent surface tack. The surface of cured silicone elastomers is sometimes characterised by a high coefficient of friction (CoF), some degree of tackiness and a tendency for blocking (sticking to itself by virtue of chemical affinity).

High friction is desired in applications where the silicone elastomer part needs to be well positioned, for example in closures or where excellent grip is required such as in dental tools. However, high friction can also be a limitation in applications where parts are sliding and soft touch is required or where dust collection, cleanability or stickiness are issues [2]. These characteristics may need to be addressed in applications that require a moulded or extruded silicone component to move or slide with minimal friction [5].

How Silicone Parts and Products are usually Fabricated with Injection Molding

Liquid Silicone Rubber (LSR) can be processed in a liquid injection molding (LIM) process. The liquid raw material is mixed from two separate components in a ratio of 1:1 and injected via a cold-runner-system into a hot mold. Curing of the parts in the mold takes place within seconds, therefore offering the advantage of fast cycling and production of large quantities quickly.

Due to the flexibility in design and tooling, LSR injection molding is ideal for the production of complex geometries and can consolidate various functional features into a single part. LIM offers significant advantages in terms of product reliability and total cost of ownership. [8]

Advantages of LSR molded parts

Liquid Silicone Rubber is perfect for a lot of high volume component or product manufacturing as it is durable, non-reactive, stable, and can resist extreme temperatures without losing its properties. Unlike thermoplastics, LSR is generally a lot more flexible and therefore often used in medical and other technical applications where light weight, flexible parts such as tubing are required.

- **Limitless design** – Enables production of part geometries and technical solutions not possible otherwise
- **Consistent** – Provides the highest consistency in product dimension, precision and overall quality due to lean manufacturing processes
- **Pure** – Silicone is one of the most extensively tested biomaterials with a long history of safe use
- **Precise** – Flashless, wasteless tool design concepts for parts from 0.002 grams to several hundred grams in weight
- **Reliable** – Using latest technology in machinery, tooling and automation
- **Quality** – ‘0’ Defect Quality Level through in-process controls
- **Fast** – Enables highest volume production as a result of short cycle times; from several thousand to millions
- **Clean** – Utilizing state-of-the-art processing techniques and production in Class 7 and 8 cleanrooms
- **Cost-effective** – Offers lowest Total Cost of Ownership (TCO) for the customer [8]

Surface Finishes of Silicone

The surface finish of silicone products matches the mold texture down to the micron level. Surface finish can be dull, very shiny, or include part identification marks. Surface finish has a direct bearing on the coefficient of friction. Textured surfaces provide better part releases when molding than polished surfaces [1]. The surface of Silicone rubbers is typically quite sticky, particularly the softer grades. Sometimes this can present problems in an end user's application.

The term "surface finish" refers to a surface's final texture at the end of production. Surface finished is defined by three characteristics: lay, waviness, and roughness. These small deviations, when compared to a perfectly flat ideal surface, become the identifying factors of an object's surface finish. The casting finishing process occurs as pre-molded and cooled cast assemblies are ground down or otherwise altered to produce a specified texture on an item's exterior [2].

To prevent surface tackiness in silicone rubber, meaning they tend to be prone to dirt adhesion, and also suffer frequently from adhesion of the sealing resin (the molding resin) within the parts feeder. Adhesion refers to the bond between two adjacent materials and is related to the force required to affect their complete separation. Surface preparation is required and use in manufacturing process since adhesive may cause several failures [7];

- Cohesive failure (silicone breaks)
- Adhesive ruptures leaving adhesive on both substrates involved in the bond
- Adhesive failure (bond breaks):
- Adhesive pulls cleanly away from the substrate

Surface Preparation of Silicone Substrate

There are many options of surface preparation of the substrate (thin slice of silicone) [7]:

1. **Mechanical roughening**
   - Sandpaper
   - Sand blasting
   - Metal wool

2. **Chemical treatment**

   Chemical treatment is the process of treating a clean surface by chemical means. The chemical nature of the substrate surface is altered to make it highly receptive to adhesion

   Examples:

   - Etching with oxalic acid/ sulfuric acid/distilled water
   - Etching with hydrofluoric acid/distilled water

3. **Use of primers**
    - One-component, no mixing
    - Promote adhesion to difficult-to-bond substrates
    - Apply in thin coats (0.5 mil)
    - Dry at room temperature and ambient humidity conditions
    - Allow the primer to air-dry for at least 30 minutes before applying silicone
    - When drying, avoid touching the primer or allowing it to be exposed to dust or water
    - Primers
    - Flame treatment
    - High temperature flame which oxidizes the surface of the substrate and provides new functional groups
    - Corona treatment
    - High voltage, high frequency discharge in air; another oxidation method, in which new functional groups are produced on the surface
    - Plasma treatment
    - Neutral and charged species created by a discharge in the presence of a gas

Reducing Surface Friction on the Finished Product

There are several ways to reduce this tackiness and reduce the coefficient of friction [6]. A number of techniques are available for reducing the surface friction of elastomeric parts such as surface texturing, lubricating fluids or vapour deposition coatings. However most of these have limitations in terms of application effectiveness, biocompatibility, mechanical performance, durability or processability [2].

1. Talcum Powder

The simplest way is through the addition of talcum powder, wiping this uniformly across the product's surface. While this option is very effective and carries no extra cost, there is the possibility of the talc being washed off. In some applications, talc is considered a contaminant [6].

2. Fluorination treatment

A more permanent solution is achieved by applying a special fluorination treatment. Products are placed in a chamber and a chemical reaction is performed, changing the surface properties of the Silicone without changing any of the physical characteristics. The resulting smooth silky feel of the Silicone is not, with this technique, simply a coating, but is a part of the product itself and therefore retains reduced friction for a useful lifetime. Dirt and dust attraction is also significantly reduced [6].

3. LSR (Liquid Silicone Rubber) topcoat

A third option is applying a LSR (Liquid Silicone Rubber) Topcoat. This proprietary liquid silicone coating technology yields the best results when sprayed onto the product. While this option is considered mid-range in terms of cost, it is not suitable for more mechanically wearing applications. This is because (unlike with fluorination) this method only gives the silicone a superficial coating, not penetrating beneath the skin [6].

As medical device designers account for friction, one solution is self-lubricating liquid silicone rubber (LSR), which eliminates an extra step to apply lubrication. Another solution is the use of a low CoF silicone coating applied to the surface and then cured to chemically bond the coating to the substrate for a non-tacky surface [5].

Liquid silicone rubber (LSR) top coat is a two-component liquid silicone material that forms a colourless matt surface finish. It can be applied using standard coating processes to silicone elastomer substrates to provide reduced surface friction. It is particularly suitable for health-care applications because it provides potential biocompatibility, good adhesion to silicone elastomer substrates and it is sterilisable [2].

An LSR top coat can be applied on surfaces that are dust and grease free (but otherwise untreated) by spraying, brushing or dipping. It cures quickly at high temperatures (150-180°C) in a ventilated hot-air oven. If the substrate cannot withstand high curing temperatures, a temperature of 100-120°C is sufficient although the curing time would need to be extended to approximately 10-30 min. Experience shows that the amount of coating that is applied is typically 0.2-0.6 g/cm^2. The coating can also be applied to silicone tubing [2].

A topcoat based on a silicone elastomer can contain fluids which improve the antifouling effect, in particular:

1. Methylphenyl Polysiloxane oils
2. A hydrocarbon-based liquid compound, for example a poly- olefin,
3. A plasticizer,
4. A lubricating oil,
5. Liquid paraffins and waxy masses of the petrolatum type,
6. A thermoplastic polymer such as poly(vinyl chloride),
7. A vinyl chloride vinyl acetate copolymer, or
8. Cationic, anionic, nonionic or amphoteric surfactants.

In order to form the silicone elastomer coating, the silicone formulations generally used involve a silicone oil, generally a reactive poly(dimethyl siloxane) with hydroxylated endings, which are optionally pre functionalized with a silane so as to have alkoxy ends, a crosslinking agent and a polycondensation catalyst, conventionally a tin salt or an alkyl titanate, a reinforcing filler and other optional additives such as bulking fillers, adhesion promoters, and dyes.

The catalysts which are used are based on tin, titanium, or amine or compositions. Catalysts based on tin and on titanium are very effective [9].

LSR top coats used in the medical industry

In the medical and pharmaceutical industries, some LSR coatings require a solvent which has hazardous characteristics, while the others are solvent free. For example, Momentive Performance Materials produces SR Top Coat TP3719 which is particularly suitable for medical applications because it is biocompatible (tested to USP Class VI and 21 CFR 177.2600), free from solvents, and can be applied by standard methods such as spraying or dip coating. LSR Top Coat TP3719 is applied to surfaces which are free from dust and grease but are otherwise untreated. After it has been applied it is cured at temperatures of between 100°C and 180°C. The coefficient of friction on polydimethylsiloxanes is reduced by over 40% with excellent substrate adhesion. In addition, Momentive Performance Materials also produces the LSR 4000 series of liquid silicone rubbers specifically for medical and pharmaceutical applications. All materials in the LSR 4000 series are tested in accordance with USP Class VI and with selected tests as defined by ISO 10993. Additional tests can be performed on request. They comply with FDA Guideline 21 CFR 177.2600. All batches of the LSR 4000 product series are tested in accordance with European Pharmacopoeia EP VI 1.3.2, confirming that the materials meet the biocompatibility requirements of the medical industry [10].

LSR top coats used in the food industry

In the food packaging industry, food processing and packaging equipment needs to be kept lubricated just like other types of equipment. Because the equipment comes in contact with products that are meant to be consumed, however, it is extremely important to use lubricants that are safe for human consumption. You also need a product that does not have an odor, a flavor, or a color that will change the taste, appearance, or flavor of your food.

That's where food grade silicone spray comes in. This spray is non-toxic and safe to use around food, making it a must-have for keeping food processing and packaging equipment lubricated and to prevent rust and corrosion. It can also make the cleanup process easier by preventing food from sticking to equipment.

Food grade silicone spray is an odorless, colorless, and tasteless spray-on lubricant that has been certified safe for consumption. The spray has multiple uses, but it is most commonly used in food processing to lubricate metal-to-non-metal surfaces. It can also be used during storage of equipment to prevent corrosion. Food grade silicone spray also prevents food from sticking and gumming up processing machines such as grinders and saws.

The dry spray evaporates quickly, leaving behind a dry film that protects equipment. Wet spray products leave a grease-like coating. Both types work well to reduce friction and prevent food from sticking to surfaces. Food grade silicone spray can be used on a wide variety of surfaces, including metal, plastic, rubber, and O-rings. There are two different types of food grade silicone spray. There is a wet version that leaves a grease-like coating, as well as a dry version that creates a dry film. The dry version does not attract dust or product debris, which works well for packaging applications. Both types stay in place well and work for vertical and overhead applications. Food grade silicone spray offers exceptional versatility and can be used on a wide range of surfaces. It also resists moisture, so it stays in place even in damp environments. It is colorless, odorless, and tasteless, so it will not alter the flavor, aroma, or appearance of any food product. Since it is completely non-toxic, it is safe for use on surfaces and equipment that come in direct contact with food. It is effective in temperatures ranging from -40 degrees Celsius to +200 degrees Celsius [11].

- **Self-lubricating LSRs**

  The traditional solution to these friction challenges requires medical device manufacturers to apply a silicone lubricant onto the moulded part as a separate manufacturing step, however, self-lubricating LSRs are now available. The lubricity is built into the silicone elastomer system which yields a lubricious surface on the moulded component. The elastomer system is formulated with a proprietary additive that elutes out over time after vulcanisation. The performance of many medical devices depends upon minimising friction at the interfaces between various components, and self-lubricating LSRs provide the basis on which to produce effective results [5].

Potential uses for self-lubricating silicone elastomers include balloons, valves, stoppers, O-rings, silicone devices with moving or sliding parts and parts that require assembly [5].

Both lubrication options provide advantages for the healthcare industry. Low CoF coatings are ideal, not only for their performance relative to friction reduction and regulatory concerns, but also because they achieve critical performance goals with negligible impact on the mechanical properties of the silicone substrates they coat. Therefore, a silicone device that must bend, twist, elongate, etc., can handle this movement, coated or uncoated, without cracking, flaking or peeling. Self-lubricating silicone elastomers may be chosen to reduce the number of processing steps required; the elastomer can also be specified with the physical properties and level of lubrication needed for the application [5].

- **Low CoF silicone coatings**

  Other methods to overcome the high degree of surface tack and blocking with silicone elastomers include cured silicone coatings. When applied to the surface of the part and cured to chemically bond to the substrate, the coating mimics the mechanical properties of the underlying substrate. The outcome is a “dry” lubricity that reduces the CoF on the surface of silicone parts and eliminates concerns about migration, leaking or rubbing off that are commonly associated with traditional lubricants [5].

  Coating options differ in how they are designed to cure e.g heat cure (HTV) or room temperature vulcanisation (RTV). With approximately the consistency of water, the coatings can be applied by dipping, but spraying is recommended. It achieves a smooth finish that results in more than a 50% decrease in the CoF when compared to a non-coated silicone [5].

  Coatings that lower the coefficient of frictions (CoF) [can be] solvent based, so your process must tolerate the use of solvents. When cured, the coating is completely dry and non-migrating.

  A low CoF coating will decrease the static coefficient of friction by up to 74 % and the kinetic coefficient of friction by up to 54 % on a typical LSR. In addition, the coating will increase the resistance to abrasion. Static friction is the force needed to break the initial friction force so that the two surfaces can move relative to each other. Dynamic friction pull force is that force needed to maintain the motion once it has been initiated.

  There are two types of curing mechanisms available for the coatings: platinum catalyzed for platinum catalyzed rubbers (like most LSRs and HCRs) or moisture curable for Tin-containing silicones [12].

Applying low CoF coatings

The application of platinum catalyzed coatings are as follows:

Mixing

For two-part, platinum catalyzed dispersions, mixing Part A into Part B (instead of Part B into Part A) is important especially when using a dispersion with high solids content. Thoroughly stir individual components prior to addition to ensure homogeneity. Mix in a 1:1 ratio by weight. Do not use wooden spatulas to mix and avoid the use of latex gloves. Exercise care to prevent solvent loss during deairing. Accomplish additional dilution for thin film applications by adding appropriate solvent. Mixer design/size/type, blade/propeller type, shear/RPM levels, and heat generated during mixing, are important parameters and should be addressed in order to have an adequately mixed dispersion.

Vacuum Deaeration

Remove air entrapped during mixing by common vacuum deaeration procedure, observing all applicable safety precautions. Slowly apply full vacuum to a suitable container of at least four times the volume of material being de-aired. Hold vacuum until bulk deaeration is complete.

Coating and Application

The part being coated with the dispersion should be free of contamination, should not inhibit the cure, and should be able to withstand the cure cycle. Although the Nusil's coating may be applied by means of dipping or brushing, it has been found that optimal results are obtained through spraying techniques. The following instructions apply to airbrush as well as retouch/refinish type spray equipment on parts up to 8” diameter. Parameters may differ based on spray equipment used and the size and geometry of the part to be coated.

Clean the surface to be coated thoroughly with an appropriate solvent and lint-free cloth or foam wipe. Allow the solvent to evaporate completely.

Thoroughly stir or shake individual components prior to blending to ensure homogeneity. Mix in a 1:1 (Part A: Part B) ratio by weight.

Due to low viscosity of [the example] coating, material may be allowed to self-deaerate.

Set air pressure to approximately 20 psi to give a slow flow of material as opposed to a strong stream. Adjust nozzle opening to the point where the material begins to get atomized.

Hold the nozzle 2 – 4 inches from the substrate and apply the coating in a slow and steady up/down or side/side motion. The substrate should be evenly wetted with a fine layer, but not soaked to a point where the coating is pooling or dripping. A final sweeping pass at a distance of 4 – 6 inches may give the coating a more uniform appearance.

Allow the bulk of the solvent to evaporate in an area with good airflow and ventilation, such as under a fume hood. This should be accomplished in about 3 – 10 minutes depending on the ambient temperature and airflow.

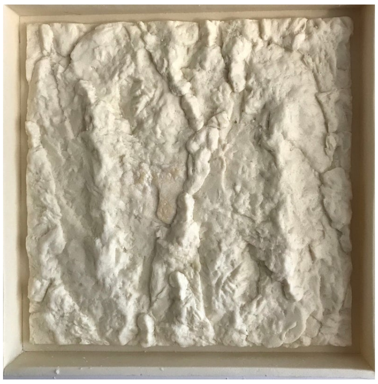
Cure the coating with temperature as suggested on the Standard Material Certification. The material may cure at lower temperatures, but the rate of cure should be determined through trials.

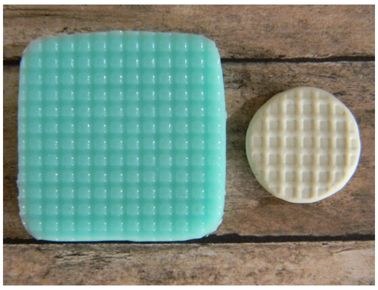
Cures in contact with most materials common to biomedical assemblies. Exceptions include:

sulfur-cured organic rubbers, latex, chlorinated rubbers, some RTV silicones and unreacted residues of some curing agents [13].

Mold Textures for Silicone Products (Photos)

The surface finish of silicone products matches the mold texture down to the micron level. Here are some examples of mold texture for silicone products:

Pictures	Definition	Source
	Leather texture	https://www.etsy.com/listing/215729523/leather-silicone-texture-impression-mat
	Stone texture	https://www.etsy.com/listing/848441395/silicone-mold-stone-texture?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=Silicone+Texture&ref=sc_gallery-1-4&plkey=b8450aad7eb403e849cad109e78c7b710154e973%3A848441395&frs=1

	Crochet Texture	https://www.etsy.com/listing/539477735/crochet-silicone-mold-crochet-texture?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=Silicone+Texture&ref=sc_gallery-1-7&plkey=93a77d010c050608eba6d97f672f8ac8ce7738e7%3A539477735
	Waffle Texture	https://www.etsy.com/listing/546756561/silicone-flexible-mold-waffle-texture?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=Silicone+Texture&ref=sr_gallery-1-21&organic_search_click=1
	Fish Texture	https://www.etsy.com/listing/751728901/mermaid-fish-scale-silicone-mold-diy?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=Silicone+Texture&ref=sr_gallery-1-34&organic_search_click=1&frs=1

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APPENDIX A

Standardized surface finishes for plastic injection molds based on The Society of the Plastics Industry [1]

Finish	**SPI* standard**	**Finishing Method**	**Typical surface roughness Ra (μm)**
Super High Glossy finish	A-1	Grade #3, 6000 Grit Diamond Buff	0.012 to 0.025
High Glossy finish	A-2	Grade #6, 3000 Grit Diamond Buff	0.025 to 0.05
Normal Glossy finish	A-3	Grade #15, 1200 Grit Diamond Buff	0.05 to 0.10
Fine Semi-glossy finish	B-1	600 #Sand Paper	0.05 to 0.10
Medium Semi-glossy finish	B-2	400# Sand Paper	0.10 to 0.15
Normal Semi-glossy finish	B-3	320#Sand Paper	0.28 to 0.32

Fine Matte finish	C-1	600 Grit Stone	0.35 to 0.40
Medium Matte finish	C-2	400 Grit Stone	0.45 to 0.55
Normal Matte finish	C-3	320 Grit Stone	0.63 to 0.70
Satin Textured finish	D-1	Dry Blast Glass Bead #11	0.80 to 1.00
Dull Textured finish	D-2	Dry Blast #240 Oxide	1.00 to 2.80
Rough Textured finish	D-3	Dry Blast #24 Oxide	3.20 to 18.0
Machined Marks	–	–	3.20 (with visible machining marks)

SPI Surface Finish - Plastics and Metal Standard Scale

Types of Finishes	Current SPI Finish Numbers		Description and Previous Finish Numbers		Roughness Comparison R.A.
Diamond	#3 Diamond Buff	**A1**	is comparable to	#1	0-1
	#6 Diamond Buff	**A2**	is slightly finer than	#2	1-2
	#15 Diamond Buff	**A3**	has more imperfections than		2-3
Paper	600 Grit	**B1**	is finer than	#3	2-3
	400 Grit	**B2**	is slightly finer than		4-5
	320 Grit	**B3**	is comparable to		9-10
Stone	600 Stone	**C1**	is finer than	#4	10-12
	400 Stone	**C2**	is slightly finer than		25-28
	320 Stone	**C3**	is comparable to		38-42
Dry Blasted	#11 Glass Bead	**D1**	is finer than	#5	10-12
	240 Aluminum Oxide Blast	**D2**	is comparable to		26-32
	#24 Aluminum Oxide Blast	**D3**	is a little more coarse than		190-230

SPI surface finish standard chart (https://www.spifinish.com/technology/)

APPENDIX B

VDI 3400 Surface Draft Angle | VDI Draft Angle [5]

- DA-PA = Drafting Angle for Polyamide
- DA-PC = Drafting Angle for Polycarbonate
- DA-ABS = Drafting Angle for Acrylonitrile-Butadiene-Styrol
- **Glass-reinforced materials require more drafting.**

VDI	Ra	Rz,	DA-PA	DA-PC	DA-ABS
12	0,40	1,5	0	1,0	0,5
15	0,56	2,4	0,5	1,0	0,5
18	0,80	3,3	0,5	1,0	0,5
21	1,12	4,7	0,5	1,0	0,5
24	1,60	6,5	0,5	1,5	1,0
27	2,24	10,5	1,0	2,0	1,5
30	3,15	12,5	1,5	2,0	2,0
33	4,50	17,5	2,0	3,0	2,5
36	6,30	24,0	2,5	4,0	3,0
39	9,00	34,0	3,0	5,0	4,0
42	12,50	48,0	4,0	6,0	5,0
45	18,00	69,0	5,0	7,0	

Why draft angle injection molding

- Reduces the chance of damage to the part due to friction during release
- Reduces wear and tear and chances of damage to the mold
- Ensures a uniform, smooth, unscratched finish when required
- Ensures the integrity and uniformity of other surface finishes and textures
- Reduces overall cooling time by lessening or eliminating the need for unconventional ejection setups
- Most, if not all, of these benefits offer either direct or indirect overall production cost reductions

Ra is calculated by an algorithm that measures the average length between the peaks and valleys and the deviation from the mean line on the entire surface within the sampling length. Ra averages all peaks and valleys of the roughness profile and then neutralizes the few outlying points so that the extreme points have no significant impact on the final results [5].

Rz is calculated by measuring the vertical distance from the highest peak to the lowest valley within five sampling lengths, then averaging these distances. Rz averages only the five highest peaks and the five deepest valleys—therefore, extremes have a much greater influence on the final value [5].

APPENDIX C

Yick Sang (YS) Texture Standards

Series Number	Ry (um)	Rz (um)	Ra (um)	Draft Angle	Polishing Finish
YS-20001	6.02	4.73	1.1	1°	1000#
YS-20002	11.65	7.96	2.14	1.5 °	800#
YS-20003	13.61	9.09	2.75	2.5 °	800#
YS-20004	17.38	13.24	3.85	2.5 °	800#
YS-20005	18.8	13.85	3.85	3°	800#

YS-20006	17.68	12.54	3.53	3°	600#
YS-20007	20.17	15.35	4.5	3°	600#
YS-20008	23.81	16.49	4.75	4.5 °	600#
YS-20009	34.82	27.8	8.26	3.5 °	600#
YS-20010	24.97	18.6	5.46	3.5 °	600#
YS-20011	26.63	19.5	5.55	4.5 °	400#
YS-20012	37.71	29.23	8.77	4.5 °	400#
YS-20013	23.81	21.03	5.72	3°	400#
YS-20014	26.94	23.37	6.2	3°	400#
YS-20015	21.56	17.52	5.35	3°	400#
YS-20016	30.23	29.84	7.77	4°	400#
YS-20017	22.86	20.56	4.88	4.5 °	400#
YS-20018	20.01	18.25	4.4	5°	400#
YS-20019	12.4	8.51	2.26	1.5 °	400#
YS-20020	13.54	9.35	2.79	2°	400#
YS-20021	18.8	13.46	3.94	2.5 °	400#
YS-20022	23.66	17.67	4.99	3°	400#
YS-20023	32.47	24.5	6.91	5°	400#
YS-20024	30.31	21.2	6.37	4.5 °	400#
YS-20025	35.82	27.67	7.8	6.5 °	400#
YS-20026	35.07	28.18	7.51	7°	400#
YS-20027	26.92	22	7.05	4°	400#

YS-2028	47.82	38.72	11.94	4°	400#
YS-20029	36.82	3.36	8.96	3°	400#
YS-20030	31.56	27.7	7.9	3°	400#
YS-20031	28.62	31.9	7.9	4.5 °	800#
YS-20032	30.28	25	8.86	3.5 °	600#
YS-20033	34.73	31.13	10.28	3.5 °	800#
YS-20034	31.13	25.03	5.67	8°	400#
YS-20035	35.65	33.8	7.65	9°	400#
YS-20036	33.64	26.15	6.77	11°	1000#
YS-20037	4.35	3.37	0.56	0.2 °	1200#
YS-20038	4.28	3.64	0.69	0.2 °	1200#
YS-20039	6.55	4.35	0.92	0.3 °	1200#
YS-20040	7.76	5.54	11.09	0.5 °	1000#
YS-20041	5.37	4.1	0.78	0.5 °	1000#
YS-20042	8.09	5.32	1.2	1°	1000#
YS-20043	15.51	9.67	2.52	1.5 °	1000#
YS-20044	12.9	8.17	2.19	1°	1000#
YS-20045	12.02	8.02	2.12	1.5 °	1000#
YS-20046	19.3	12.93	3.26	2°	800#
YS-20047	14.39	9.53	2.56	1.5 °	800#
YS-20048	15.18	10.03	2.65	1.5 °	800#
YS-20049	34.24	30.59	8.96	3°	400#

YS-20050	34.87	32.44	8.09	3°	400#
YS-20051	27.95	25.19	6.9	4°	400#
YS-20052	25.06	21.56	5.74	3°	400#
YS-20053	23.99	18.6	4.61	3°	400#
YS-20054	30.01	25.17	6.98	4.5 °	320#
YS-20055	22.99	14.32	2.61	3°	800#
YS-20056	26.03	17.35	4.81	2°	800#
YS-20057	23	15.7	4.14	2.5 °	800#
YS-20058	25.85	18.12	4.97	3.5 °	800#
YS-20059	27.52	18.42	5.4	3°	800#
YS-20060	35.12	24.76	6.55	3°	600#
YS-20061	27.08	18.57	4.88	4°	600#
YS-20062	30.58	21.48	6.27	3°	600#
YS-20063	24.32	20.84	6.73	3°	400#
YS-2064	21.55	17.42	5.51	3.5 °	400#
YS-20065	25.73	22.62	6.75	3°	400#
YS-20066	21.4	18.22	5.51	3.5 °	400#
YS-20067	15.53	11.59	3.3	1°	1000#
YS-20068	21.18	15.3	4.29	1.5 °	800#
YS-20069	42.12	31.38	9.17	5°	400#
YS-20070	23.27	21.47	6.28	3°	600#
YS-20071	34.21	30.07	8.31	4.5 °	400#

YS-20072	37.85	33.38	9.75	9°	320#
YS-20073	26.78	22.48	5.49	9°	400#
YS-20074	23.49	19.64	5.41	7°	400#
YS-20075	19.38	12.32	3.68	8°	320#
YS-20076	25.4	18.23	5.48	7°	320#
YS-20077	20.37	14.48	4.06	8°	320#
YS-20078	26.96	20.55	6.15	9°	320#
YS-20079	18.23	14.18	4.27	9°	320#
YS-20080	22.74	17.43	5.01	11°	320#
YS-20081	27.58	22.16	6.04	9°	320#
YS-20082	19.79	14.54	3.95	9°	320#
YS-20083	14.7	9.46	2.88	12°	320#
YS-20084	22.84	17.18	5.45	11°	320#
YS-20085	27.71	20.99	5.59	6°	400#
YS-20086	32.24	16.04	4.87	11°	320#
YS-20087	32.89	25.96	7.4	4.5 °	400#
YS-20088	36.76	29.35	8.53	4.5 °	400#
YS-20089	24.85	20.28	5.26	4°	400#
YS-20090	32.24	23.38	6.9	6.5 °	400#
YS-20091	7.97	5.49	1.27	3°	400#
YS-20092	24.75	19.76	5.42	4.5 °	400#
YS-20093	23.39	17.9	5.08	4.5 °	400#

YS-20094	15.38	10.31	2.98	4°	400#
YS-20095	20.76	17.29	4.06	4°	400#

Please also consider the roughness conversion for Chinese manufacture of textured plastics against European or American standards here:
https://upmold.com/vdi-3400-vs-spi-finish-surface-roughness-comparison/

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