Material Contributions to Defects on Diamond Turned Surfaces

PRECISION-OPTICAL ENGINEERING

DM 004

Application Note

Diamond turning is an extraordinarily versatile technique for producing a variety of surfaces in a variety of materials. Materials include:

- aluminium
- copper
- brass
- germanium
- ZnS
- ZnSe
- Silicon
- Chalcogenide glasses

Defects in machined surfaces

Surface defects caused by diamond turning can be divided into two main areas: fine surface features of the component known as microscopic defects and surface form error of the component which are termed macroscopic defects. Although there are many factors which contribute to both microscopic and macroscopic defects, effects due to the materials used themselves play an important role. It is useful to understand these contributions so that the most suitable material can be chosen for any particular component.

Microscopic defects

Some of the properties of a material that can cause an increase in surface defects and surface texture include material hardness, inhomogeneity and surface impurities. Hardness and ductility lead to increased tool wear. Inhomogeneity and surface impurities are particularly applicable to metals and metal alloys. Aluminium alloy can present difficulties because of the presence of other elements within the alloy. For instance, impurities on the surface of an aluminium mirror such as localised concentrations of silicon produce tears in the surface as the tool passes over them. These tears can normally be ignored when the component is being used in the infra-red waveband. However, for visible applications or applications using high power lasers these surface tears can become significant. They are also difficult to detect as they can generally only be seen under a high power microscope. Even using a surface roughness measuring instrument they are difficult to quantify, as they will not add significantly to the most common surface roughness parameters, Ra or Rq. Ra is the Roughness Average and is the industry standard for roughness measurement, defined by the equation:

$$R_a = \frac{\sum_{n=1}^{N} |y_n|}{N}$$

over sample length, L, where y_n are sample heights, as shown in the figure overleaf.

R_q is the RMS Roughness, which is the roughness measurement appropriate for statistical analysis. It is defined by:

$$R_q = \sqrt{\frac{\sum_{n=1}^{N} y_n^2}{N}}$$

over sample length, L.

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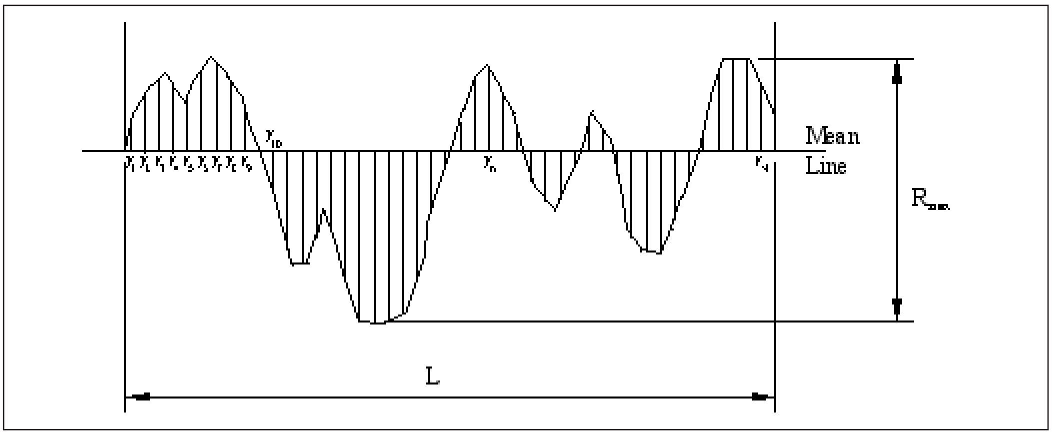

Another material property that can often be problematic is a material's grain structure. This is an effect where the grain structure becomes pronounced and occurs in metals such as aluminium and copper alloy as well as some materials such as ZnS and ZnSe. These effects usually occur when the machining process has not been optimised such as with spindle imbalance or tool chatter.

Macroscopic Defects

Some of the properties of materials lead to errors in the form of a surface. Two of these properties are residual stress and grain or crystal boundaries.

Residual stress

If a material contains residual stress then when it is machined the stress may be released and it may bend, thus affecting the surface form. The material where this is particularly problematic is aluminium alloy. In the machining of aluminium alloy, stress can be induced depending on how the alloy is formed. The alloy can be extruded into a square or circular section bar with the grain running in the direction of the extrusion or rolled into plate with the grain running parallel to the plate surface. Plate material acts like a laminated surface. When material is removed it will spring to a new shape. For bar material, if the material is removed perpendicular to the grain structure then less stress is released. To minimise the problems of residual stress within aluminium alloy the material should always be stress relieved before diamond turning. Plate material should be avoided as even stress relieving does not eliminate the effects of its laminated structure. Mirror blanks should always be taken from a cross section of bar material.

Grain or crystal boundaries

Many materials that can be diamond machined have a crystal structure or grain structure. Each grain or crystal area will have slightly different properties. Therefore, if the cutting process is not optimised, discontinuities can occur at crystal or grain boundaries. This can be particularly obvious when machining polycrystalline germanium or silicon. Often polycrystalline germanium is failed single crystal germanium with just a few crystal grains. When it is machined the crystal structure can be seen visually, and when the surface is measured there are steps in the surface at the crystal boundaries. It is usually wise to always specify single crystal germanium and silicon for diamond turning applications.

Similar effects can occur with special copper alloys with large grain structures.

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