BORE QUALITY OF SHOTGUN BARREL BLANKS

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This paper provides a novel manner of shotgun barrel bore surface texture specification. The current state of shotgun barrel blank bore surface texture specification and measurement is analyzed. Comparative measurements of samples with good and inferior surface quality are used to demonstrate the shortcomings of current specifications. In seeking improvement, six profile parameters are evaluated and their sensitivity to prevalent surface imperfections is determined. Similarly, six areal parameters are evaluated, and suitable measurement settings are determined for the most sensitive one. The parameters are ranked according to their level of sensitivity to change in bore surface quality. Based on all of the above, profile and areal parameters particularly suitable for specification of shotgun barrel bore surface texture are singled out.

KEYWORDS

surface texture, surface metrology, firearms, shotguns, barrel blanks, radial forging

1 INTRODUCTION

Quality is defined as a degree to which a set of inherent characteristics fulfills requirements. As such, it is always connected with explicitly specified or implicitly expected requirements. This is true for all common industrial products, as well as special products like sporting and hunting shotguns (Fig. 1).

Figure 1. Over/under shotgun, www.czub.cz

Quality of a shotgun can be expressed as the ability of its inherent characteristics to satisfy the needs, requirements and expectations of its users, in our case shooters and hunters. Naturally, it depends on the quality of all individual components of the shotgun.

A barrel of a shotgun is arguably the paramount among those components and surface texture of the bore is one of its key characteristics.

This paper deals with providing an unambiguous, previously unpublished manner of shotgun barrel bore surface texture specification based on surface texture measurements of barrels of different quality.

2 CURRENT SURFACE TEXTURE REQUIREMENTS

Barrel bore surface texture requirements binding in the Czech Republic are defined by a Czech Technical Standard CSN 39 5003. Act No. 156/2000 Coll., and its implementation in Decree No. 335/2004 Coll. These state, that no imperfections visible with the naked eye may be present on the bore surface, and that the surface must be sufficiently polished, with *Ra* not exceeding 1 µm in the guiding part of the bore or 1.8 µm in the chamber. [Decree 335/2004], [Balla 2013]

These requirements are rather simple to fulfill, and all but the cheapest barrels are manufactured to tighter tolerances of surface texture. Typically, a value of *Ra* up to 0.3 – 0.4 µm is considered acceptable. [Balla 2013]

The surface texture specification of the barrels used in our analysis requires *Ra* not to exceed 0.4 µm, while applying the 16 %-rule. [ISO 4288:1996]

3 MEASUREMENT OF BARREL BLANK SURFACE TEXTURE

Surfaces of two radially forged 12 gauge shotgun barrel blanks of different levels of quality were measured using a Taylor Hobson Talysurf CCI Lite 3D profiler. Both blanks have been measured using Mirau interferometer objectives with 20× and 50× magnification.

Each primary surface was automatically S-filtered. Afterwards, leveling and F-operation (least-square polynomial form removal) were performed manually. Consequently, all parameters were evaluated on the S-F surface resulting from each measurement.

Profile parameters were evaluated on 1024 profiles of a single evaluation length *lr*=0.8 mm obtained from S-F surfaces of measurements made with the 20× objective.

Areal parameters were evaluated on S-F surfaces of measurements made with the 50× objective.

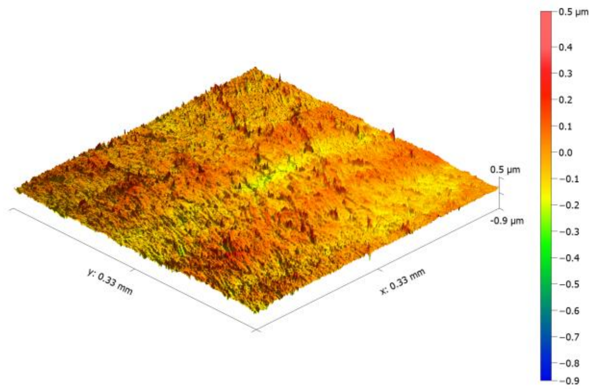

Figure 2. A 3D model of the surface of barrel blank no. 1

Blank no. 1 is an example of a good quality bore surface. As demonstrated in Fig. 2. the surface shows only a minimal number of prominent valleys and peaks. Obtained values of *Ra* range from 0.046 µm to 0.085 µm, with a mean of *Ra*=0.057 µm, which is well under upper specification limit.

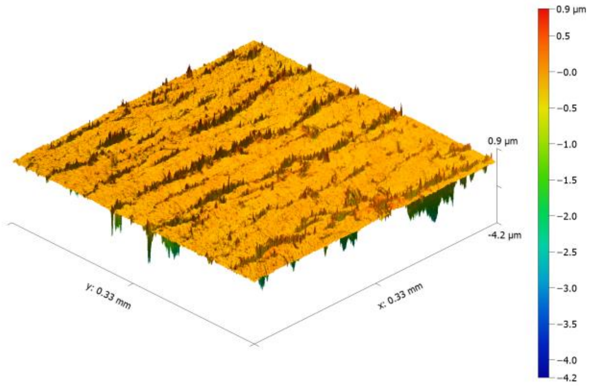

Figure 3. A 3D model of the surface of barrel blank no. 2

Blank no. 2 serves as an example of inferior quality, mainly because of presence of a large number of transversal cracks of varied length and depth, as can be seen on Fig. 3. In spite of their presence, the obtained values of *Ra* range from 0.027 µm to 0.382 µm, with a mean of *Ra*=0.107 µm, which means none of the measured values exceed upper specification limit.

Since these cracks act as stress risers, they negatively affect the barrel's strength and durability: Therefore, it appears prudent to seek a superior manner of surface texture specification.

4 PROFILE METHOD AND PARAMETERS

In order to find a potentially more suitable parameter than *Ra*, six additional profile roughness parameters were evaluated.

The root mean square deviation of the roughness profile *Rq* was chosen because it is an analogue of Ra known to be more sensitive to extreme values.

Maximum profile valley depth *Rv* and maximum height of profile *Rz* were chosen, because they could better capture the depth of the cracks present on Blank 2.

Finally, skewness *Rsk* and kurtosis *Rku* were included because of their sensitivity to isolated peaks and valleys. [ISO 4287], [Piska 2014]

Each of the parameters was evaluated on 1024 profiles consisting of a single evaluation length *lr*=0.8 mm, with the same cut-off wavelength. Mean and maximum values of each parameter were used to determine each parameter's sensitivity to the surface imperfections characterizing the measured surfaces, expressed as a proportion of value from Blank 2 to value from Blank 1.

The results of these comparisons can be seen in tables 1 and 2 below.

Par.	Blank 1 (st. dev.)	Blank 2 (st. dev.)	B2/B1 [%]
Rsk **[-]**	-0.367 (0.785)	-5.213 (2.316)	1419%
Rku **[-]**	6.949 (3.973)	47.382 (30.012)	682%
Rv **[µm]**	0.397 (0.154)	2.173 (1.147)	547%
Rz **[µm]**	0.729 (0.229)	2.599 (1.217)	356%
Rq **[µm]**	0.077 (0.012)	0.237 (0.157)	309%
Ra **[µm]**	0.057 (0.007)	0.107 (0.075)	187%

Table 1. Mean values, standard deviations and sensitivity of selected profile roughness parameters

When mean values were considered, roughness profile skewness *Rsk* was overwhelmingly the most sensitive of the selected parameters, with the relative difference of values between Blanks 1 and 2 almost double compared to the second most sensitive parameter, kurtosis *Rku*.

Parameter *Ra*, currently used in the specification, was shown to be the least sensitive of all seven.

Par.	Blank 1	Blank 2	B2/B1 [%]
Rku **[-]**	22.851	223.499	978%
Rv **[µm]**	0.792	7.257	916%
Rq **[µm]**	0.119	0.749	628%
Rz **[µm]**	1.469	8.283	564%
Rsk **[-]**	-2.798	-13.170	471%
Ra **[µm]**	0.085	0.382	449%

Table 2. Maximum values and sensitivity of selected profile roughness parameters

With maximum values, roughness profile kurtosis *Rku* was the most sensitive parameter, followed by similarly sensitive maximum valley depth *Rv*. Notably, skewness *Rsk*, which was the most sensitive parameter with mean values, appeared to be the second least sensitive of the selected parameters, most likely due to a large skewness range measured on Blank 1.

Parameter *Ra*, currently used in the specification, was again shown to be the least sensitive of all seven.

Two parameters, kurtosis *Rku* and maximum valley depth *Rv*, showed consistent sensitivity, with Rku ranking second/first and Rv third/second with means/maximums respectively. Kurtosis *Rku* will point to sharp changes in height regardless of their orientation and valley depth *Rv* can confirm the presence of valleys as opposed to peaks. Therefore, a combination of both of these parameters provides a mode of surface roughness specification superior to the currently used parameter *Ra*.

5 AREAL METHOD AND PARAMETERS OF VOLUME

In addition to parameters analogical to those used in the profile method, ISO 21578-2 defines a number of new parameters specific to the areal method of surface texture evaluation. Of these, six volume parameters appear particularly suitable for measuring prominent surface features like those present on the barrel blank bore surfaces analyzed in this paper.

These are:

- Void volume *Vv(p)*, the empty volume up to a given material ratio,
- Dale void volume *Vvv* (Fig. 4), the empty volume of dales defined by a given material ratio,
- Core void volume *Vvc*, the empty volume between two given material ratios,
- Material volume *Vm(p)*, the volume of material above of a given material ratio,
- Peak material volume *Vmp*, the volume of peaks defined by a given material ratio, and
- Core material volume *Vmc*, the volume of material between two given material ratios,

all per given unit of area and calculated from the areal material ratio curve. [ISO 25178-2], [Whitehouse 1994], [Whitehouse 1997]

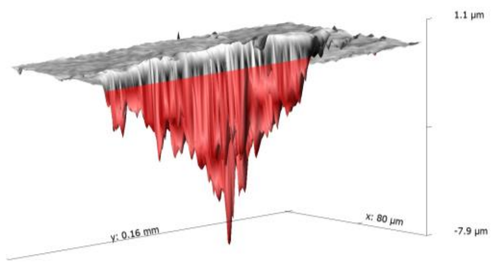

Figure 4. Dale void volume *Vvv* illustrated at *Smr*=80 %

Tab. 3 below presents the measured values of volume parameters at stated material ratios *Smr*. The last column includes the parameter's sensitivity calculated as in Tab. 1 and 2 above.

Parameter	*Smr* [%]	Blank 1 [µm³/µm²]	Blank 2 [µm³/µm²]	B2/B1 [%]
Vvv	80	4.74E-02	9.27E-03	511%
Vm	10	5.03E-03	3.28E-03	153%
Vmp	10	5.03E-03	3.28E-03	153%
Vv	10	1.15E-01	8.31E-02	138%
Vvc	10-80	6.73E-02	7.39E-02	91%
Vmc	10-80	4.88E-02	5.64E-02	86%

Table 3. Values and sensitivity of volume parameters

As can be seen in Tab. 3. dale void volume *Vvv* shows the largest, over fivefold, relative difference between Blanks 1 and 2. However, since the value of *Vvv* depends on the chosen areal material ratio, a further analysis was carried out to determine the optimal value thereof.

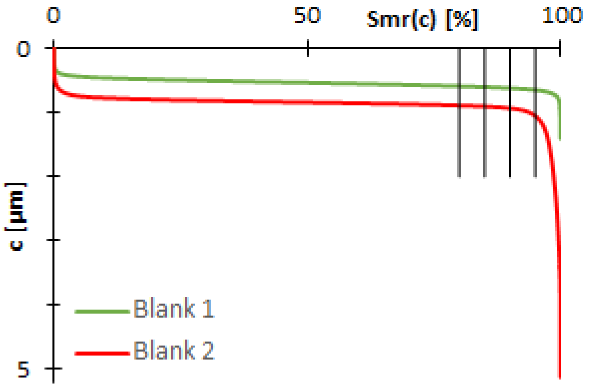

Figure 5. Areal material ratio curves of Blanks 1 and 2

Fig. 5 shows the areal material ratio curves of the two barrel blanks. It is apparent, that while both surfaces contain scarce, low peaks, the surface of Blank 2 also includes extremely deep dales. The largest relative difference in parameter values can be expected near the highest material ratio values.

Smr [%]	$Vvv_{Blank\ 1}$ [µm³/µm²]	$Vvv_{Blank\ 2}$ [µm³/µm²]	B2/B1 [%]
95	2.798E-03	3.295E-02	1178%
90	4.871E-03	4.113E-02	844%
85	6.990E-03	4.462E-02	638%
80	9.273E-03	4.738E-02	511%

Table 4. Values and sensitivity of dale void volume at different material ratios

Values of *Vvv* evaluated at different material ratios are given in Tab. 4. As could be expected based on Fig. 5. the highest relative difference was found between parameters calculated with *Smr*=95 %.

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6 CONCLUSIONS

Measurements have demonstrated, that the parameter *Ra* currently used in the specification of barrel blank bore surface texture cannot account for the types of imperfections found on radially forged barrel blanks. Parameters *Rku* and *Rv* were found to perform consistently well in detecting the transversal cracks present on the sample surface.

Areal surface texture parameter dale void volume *Vvv* was found to be sensitive to the transversal cracks. Its best suited reference areal material ratio *Smr* was determined to be 95%.

In order to improve detection of surface imperfections, parameters *Rku*, *Rv* and Vvv should be added to the barrel blank bore surface texture specification.

In a production environment, profile parameters *Rku* and *Rv* can be evaluated by currently used stylus profilers. The areal parameter *Vvv* would require using an optical instrument and cutting of the sample. However, it could readily be evaluated on the excess lengths of barrels, which are cut away after the radial forging operation. Evaluation of *Vvv* parameter could be used in case of a dispute with barrel blanks supplier.

Future research in this area may focus on determination of threshold values of selected surface texture parameters and applying a similar approach to quality control of rifled barrel bore surfaces.

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