PROCESS CAPACITY INDEXES IN THE PRODUCTION OF RIBBED BARS

INGALDI Manuela

Czestochowa University of Technology, Faculty of Management, Department of Production Engineering and Safety, Czestochowa, Poland, EU, manuela@gazeta.pl

Abstract

Process capability indexes can be defined as statistical measures of process capability: the ability of a process to produce output within specification limits. It is important especially in case of ribbed bars where all characteristics should be kept. Ribbed bars are used in reinforced concrete structures and provide a better grip of the reinforcement to the concrete due to their shapes and the same time bigger contact surface. Recipients of ribbed bars demand that they have high strength and toughness, corrosion resistance, good weldability and high fatigue resistance. The process capacity indexes can be used for evaluation of repeatability of different characteristics. Cp index determines the ability of the process to manufacture products with constant properties, while Cpk index includes both natural variability of characteristic and the position of the average value in relation to the tolerance limits. In the paper Cp and Cpk indexes were calculated for the mass of 1 m of the ribbed bars with a diameter of 10, 16 and 25 mm made of steel BSt500S.

Keywords: Ribbed bars, capacity, Cp/Cpk

1. INTRODUCTION

Together with the emerging investment and building highways, modern building shows huge demand for, among other things, ribbed bars for concrete reinforcement. Constructions of the concrete, which is connected with them, allow for significant savings in steel, aggregates, cement, wood and shorten construction time. The ribbed bars in reinforced concrete structures provide a better grip concrete reinforcement due to special shape, in which on a round core humps (ribs) are placed. Recipients of the ribbed bars demand that they have high strength and toughness, corrosion resistance, good weldability and high fatigue resistance. These properties decide whether the products are considered to be of good quality, and same time, find buyers in the market. These features must characterize by low variability [1-4].

To evaluate process capacity for the manufacture of products with constant parameters, the process capacity indexes are used. Cp index determines the ability of the process to manufacture products with constant properties, while Cpk index includes both natural variability of feature and the position of the average value in relation to the tolerance limits.

The aim of this paper is to evaluate a capacity of production process of the ribbed bars. In the paper Cp and Cpk indexes were calculated for the mass of 1 m of the ribbed bars with a diameter of 10, 16 and 25 mm made of steel BSt500S.

2. MATERIAL

Process capacity is a measure of the producer capability to produce a product which meet a tolerance. It compares the tolerance rage to the producer distribution width. The process capacity consists of two indexes. The first index of process capacity, in literature denoted as Cp, expresses the quality of the process, taking into account its control. It allows to determine the process capacity to manufacture products with constant properties. The Cp index determines how many times the range of natural variability of the features goes into its tolerance. It is calculated from the formula [5]:

$$c_p = \frac{GLT - DLT}{6s} = \frac{T}{6s} \quad (1)$$

where: GLT - the upper limit of the tolerance of the feature; DLT - the lower limit of the tolerance of the feature; T - the tolerance; s - standard deviation.

In this case, the formula considers the quantity of variation given by standard deviation and an acceptable gap allowed by specified limits despite the mean.

A value of Cp index below 1 means that the process variability is outside the range of specification. This means that the process is not capable of producing within specification and it must be improved. Many different types of industries require the Cp index of 1.33 or 1.44, sometimes more so that there is a small allowance for the mean to shift before some products go out of the tolerance.

The Cpk index has a corrected form of the Cp index. It consists of a sample in which the differences in the data within a subgroup are minimized and the differences between groups are maximized. This allows a clearer identification of how the process parameters change along a time continuum. It is calculated from the formula [5]:

$$c_{pk} = \frac{GLT - \bar{x}}{3s} \text{ if } GLT - \bar{x} \le \bar{x} - DLT \quad \text{or} \quad c_{pk} = \frac{\bar{x} - DLT}{3s} \text{ if } GLT - \bar{x} > \bar{x} - DLT \quad (2, 3)$$

where: GLT, DLT, s - as before; $\bar{x}$ - average of the sample.

Although a satisfactory Cp shows that the producer is capable to meet the tolerance, it does not show whether the product actually does it. The Cpk index takes the centering into account. A perfectly centered process will have Cp = Cpk. If Cp ≠ Cpk, it means that there is a constant factor in the process which causes that the average value of the research feature differs from the nominal value (lack of centering).

The Cpk index can be used when there is only one limit of the tolerance of the characteristic (upper or lower). While is such situation the Cp index can't be used Cp [6-9].

3. RESEARCH MATERIAL

The research rolling mill offers to its customers a wide range of the ribbed bars. In the paper results for the ribbed bars with a diameter of 10, 16 and 25 mm made of steel BSt500S were presented. The customer in his order should specify the exact dimensions, tolerance, steel grades, quantities and conditions of supply and all standards related with it, types of quality certification documents. The ribbed bars, like other metallurgical products, must meet the relevant standards requirements and those specified by customers in their orders. Major requirements for the ribbed bars made of steel BSt500S are included in the standard DIN 488. In **Table 1** mass characteristics of the research bars was presented while in **Table 2** their basic parameters.

Table1 The nominal mass of 1 m and acceptable deviation from the mass of 1 m [10]

The nominal diameter, mm	Mass of 1 m, kg	Acceptable deviation from the mass, kg	
		the lower limit	the upper limit
ϕ10	0.617	0.586	0.648
ϕ16	1.580	1.501	1.659
ϕ25	3.850	3.695	4.004

Table 2 Basic parameters of the offered ribbed bars [10]

The nominal diameter of the ribbed bar, mm	Nominal cross-sectional area of the bar, mm^2	Density, kg/dm^3
ϕ10	78.5	7.85
ϕ16	201	
ϕ25	491	

The surface of the bars should be free from cracks, blistering and abrasions. At the front of the bars, residues of the cavity, dissections and cracks visible to the naked eye are unacceptable. Surface defects such as scratches, minor scales and flattening, non-metallic inclusions, pitting, bulges, dents, scales, mill scale are acceptable, if they do not exceed 0.5 mm for the ribbed bars with a nominal diameter up to 25 mm and 0.7 mm for the bars of larger diameter [11-12].

According to the steel grade, the ribbed bars are characterized by the appropriate ribbing which depends on the steel used to their production. In **Figure 1** basic geometry of the ribbed bars made of steel BSt500S was presented. In **Table 3** the chemical composition of the steel grade BSt500S according to the appropriate standard was presented.

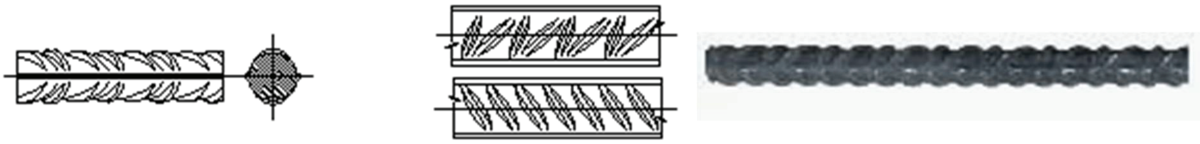

Figure 1 The geometry of the ribbed bars made of steel BSt500S [13]

Table 3 The chemical composition of the steel grade BSt500S, % mas. [14]

Steel grade	C	Mn	Si	P	S	Cr	Ni	Cu	N2	Ceq
BSt500S	0.14 0.18	0.65 0.80	0.15 0.30	max 0.040	max 0.040	max 0.25	max 0.25	max 0.35	max 0.012	max 0.50

The coefficient Ceq is called the carbon equivalent. It characterizes the usefulness of welding steel due to its chemical composition. The coefficient is determined by the following formula [15]:

$$C_{eq} \leq \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%V + \%Mo}{5} + \frac{\%Cu + \%Ni}{15} \tag{4}$$

The ribbed bars must have appropriate mechanical and technological properties, which are also described in relevant standards. In **Table 4** minimum and maximum values of basic mechanical properties for the bars made of steel BSt500S are presented. Other important mechanical properties of ribbed bars is bending test.

Table 4 Mechanical properties ribbed bars made of steel BSt500S [13]

	Value	BSt500S
Tensile strength - Rm, MPa	minimum	550
	maximum	-
Yield strengthi - Re, MPa	minimum	500
Relative elongation - A5, %	minimum	-
Relative elongation - A10, %	minimum	12

Ribbed bars are delivered with a fabrication lengths of 6 ÷ 12 m or specified in the order of up to 12 m with a permissible deviation of ± 100 mm, in approximate bundles 1.5 Mg - 4.5 Mg. It is permissible to supply 6% of the ordered mass of ribbed bars of lengths smaller or larger but not less than 6 m unless otherwise agreed in the order. The bars with a length of more than 12 m or less than 6 m can only be supplied upon request to the purchaser [10].

4. RESULTS

In the paper Cp and Cpk indexes were calculated for the mass of 1 m of the ribbed bars with a diameter of 10, 16 and 25 mm made of steel BSt500S in three consecutive years. In **Figures 2 - 4** measurements distributions relative to tolerance limits and the values of Cp and Cpk indexes during the research period were presented.

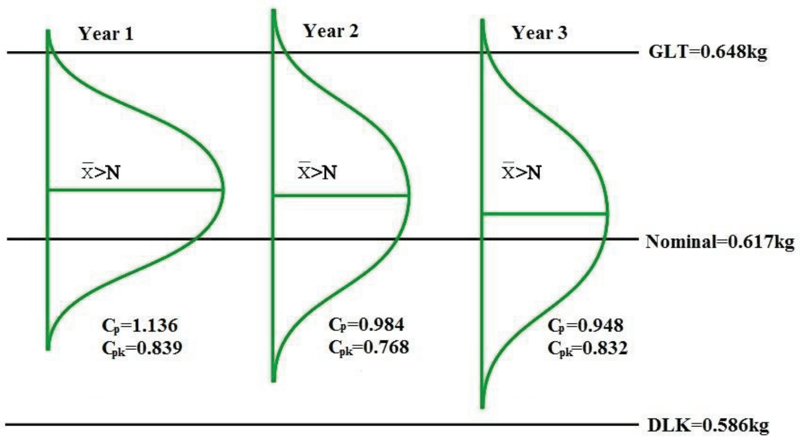

Figure 2 Process capacity indexes base on the mass of 1 mb ribbed bars with a diameter 10 mm made of steel BSt500S [own study]

During all research period lack of process capacity was noticed. Only in the first year the Cp index exceeded 1, but its value was below 1.44. In this case process variability was smaller than tolerance, but, because the process variability moved in relation to the tolerance (to the upper limit of the tolerance), there was no process capacity neither.

During the second and third research year, already Cp index showed lack of process capacity because process variation was bigger than tolerance (Cp < 1). Additionally, like during first year, there was huge movement of the process variation in a direction of the upper limit of the tolerance.

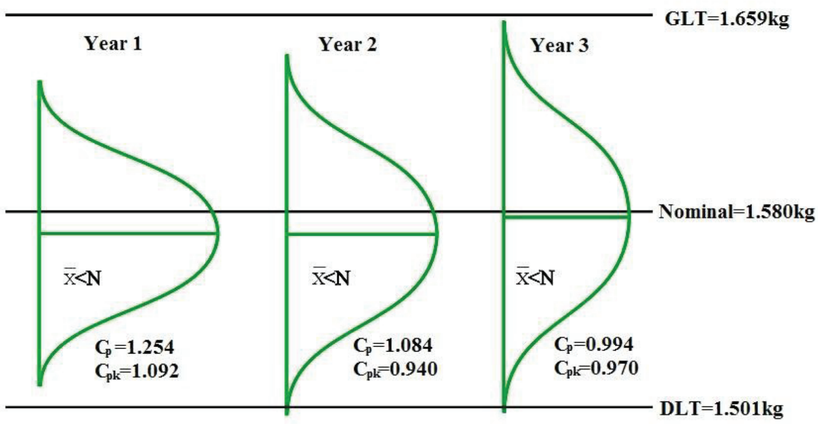

Figure 3 Process capacity indexes base on the mass of 1 mb ribbed bars with a diameter 16 mm made of steel BSt500S [own study]

In case of the ribbed bars with a diameter 16 mm, different situation than in previous example was observed. All average values for the individual years were lower than nominal values. In the last year the situation was better if it comes to the average. But due to the fact that Cp index was lower than 1, there was lack of process capacity. In first and second year Cp index was above 1 but it was not high enough, and the movement of average value in relation to the nominal value caused that also in these two years lack of process capacity was noticed.

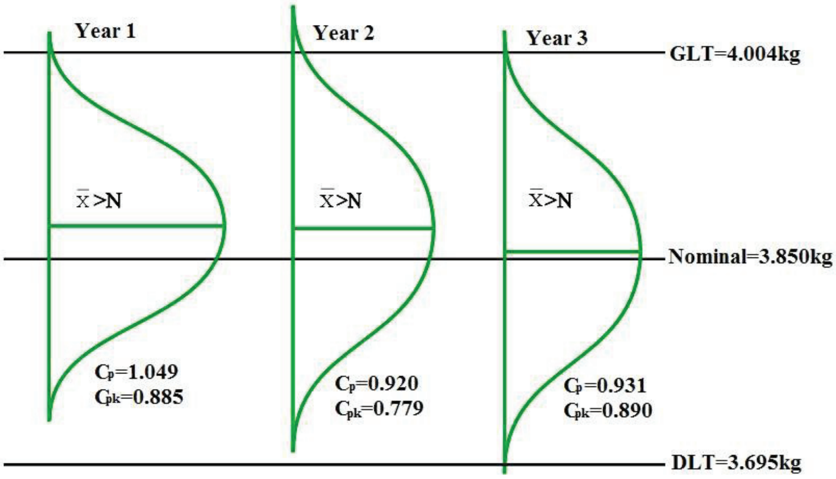

Figure 4 Process capacity indexes base on the mass of 1 mb ribbed bars with a diameter 25 mm made of steel BSt500S [own study]

Also in case of the ribbed bars with a diameter 25 mm there was lack of process capacity noticed. The average values were moved in relation to the nominal value (in the third year not too much). For the first research year process variability was minimal smaller than tolerance, during other two year bigger. What means problem with process capacity.

5. CONCLUSION

In the paper the results of process capacity research for the ribbed bars made of steel BSt500S were presented. In the research, the mass of 1 m of the ribbed bars with a diameter of 10, 16 and 25 mm was chosen. It turned out that in all cases there was lack of process capacity. It means that individual products differ from each other, that hence the standard deviation was high. So the research rolling mill was not able to produce product with completely constant parameters. What's more, the process variability in case of mass of 1 m moved in relation to the tolerance, what means that mass of some ribbed bars may not meet requirements (be outside the tolerance). Further research on the causes of such a situation and their elimination should be carried out. Since such a situation may cause that the research ribbed bars will not meet the customers' requirements.

To underline, the Cp and Cpk are well known capability indexes commonly used to ensure that a process spread is as small as possible compared to the tolerance interval (Cp), or that it stays well within specifications (Cpk).

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