Designation: D4583 – 21

Standard Practice for Carbon Black—Calculation of Process Indexes From an Analysis of Process Control Data[1]

This standard is issued under the fixed designation D4583; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers (*1*) a statistical procedure for analyzing the test data generated in the statistical process control of a carbon black manufacturing process; (*2*) a format for reporting process capability determined from the analysis of control chart data of an individual production run, and (*3*) a format for reporting process performance determined from the analysis of control chart data of an individual production run.

1.2 This practice specifically applies to the analysis of pelleted carbon black samples taken during the manufacturing process prior to storage. This practice does not apply to shipment samples taken from hopper cars or other containers or packages.

1.3 This practice is specifically designed to be used for those test methods given in Classification D1765 which specify target values. However, these techniques are applicable to other test methods on carbon black.

1.4 This practice describes the calculation for two methods of determining capability factors from an analysis of process control data.

1.4.1 Process capability (*Cp*) is a measurement of variation calculated from the process control chart data with the use of an estimated standard deviation ($\hat{\sigma}$) from the mean value of the moving range (*R*) chart. The calculation of the process capability (*Cp* and *Cpk*) indexes can be used as historical information or to predict future performance of the process, but are only valid when the process is in a state of statistical control.

1.4.2 Process performance (*Pp*) is a measurement of variation calculated from the process control chart data using sample standard deviation(s). The calculation of the process performance (*Pp* and *Ppk*) indexes are used for a historical reference of a process' performance and does not require a state of statistical control.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1765 Classification System for Carbon Blacks Used in Rubber Products

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*[4]

3.1.1 *common cause, n*—descriptor of inherent random variation in a system or process; the magnitude of the variation is within nominally accepted statistical limits.

3.1.1.1 *Discussion*—Common causes may be unidentifiable or may have known origins that are not easily controllable or cost effective to eliminate.

3.1.2 *state of statistical control, n*—process condition when only common causes are operating on the process.

3.1.2.1 *Discussion*—In the strict sense, a process being in a state of statistical control implies that successive values of the characteristic have the statistical character of a sequence of observations drawn independently from a common distribution.

3.1.3 *average moving range* $(\bar{R})$—the arithmetic mean of *n* moving ranges, $\bar{R} = \sum R/n$.

3.1.4 *Cpk index*—an index that indicates how well the common cause process variability is actually contained within the specifications. (See 6.4.)

3.1.5 *moving range (R)*—the absolute difference between consecutive, individual test values.

[1] This practice is under the jurisdiction of ASTM Committee D24 on Carbon Black and is the direct responsibility of Subcommittee D24.61 on Carbon Black Sampling and Statistical Analysis.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] *Manual on Presentation of Data and Control Chart Analysis, STP 15D,* ASTM International, 1976.

[4] *Ford Motor Company Manual* on *"Process Capability and Continuing Process Control,"* Publication No. 80-01-251. Available in packs of five from Ford Motor Company, Statistical Methods Publications, P.O. Box 1000, Plymouth, MI 48170.

3.1.6 *Ppk index*—indicates how well the common and special cause process variability is actually contained within the specifications. (See 6.6.)

3.1.7 *process capability index (Cp)*—an index that compares the magnitude of common cause process variability to the range of upper and lower specification limits (*USL* and *LSL*) without regard to where the process is centered; *Cp* index = (*USL* − *LSL*)/(6$\hat{\sigma}$). (See 6.3.)

3.1.8 *process performance index(Pp)*—an index that compares the magnitude of common and special cause process variability to the range of the upper and lower specification limits (*USL* and *LSL*) without regard to where the process is centered; *Pp* index = (*USL* − *LSL*)/(6s). (See 6.5.)

4. Significance and Use

4.1 This practice will provide the following: (*1*) a statistical summary of individual production run data plotted on a control chart; (*2*) a statistical summary of data from multiple production runs; (*3*) a procedure to relate the average and variation of these data groups to specification limits, and (*4*) indexes for comparing different manufacturing units for projecting future capabilities or as historical reference.

5. Procedure

5.1 *Sampling:*

5.1.1 In order to provide uniformity and the ability to make valid comparisons of process capability and process performance indexes, all samples used for these calculations shall be collected in the same way. Samples that are to be tested for properties on which capability or performance indexes will be calculated shall be collected as follows:

5.1.1.1 All samples shall be taken from the process at the finished pellet discharge and tested individually. Compositing of samples is not permitted.

5.1.1.2 Samples normally shall be taken every 4 h. All results obtained on material that is put into finished product storage tanks shall be included.

5.1.1.3 Averaging of results is not permitted. Each result, as defined by the appropriate test method, is to be recorded and used in performing the calculations described in Section 6.

5.2 *Process Capability:*

5.2.1 A minimum of 30 test data generated during production periods in which the process is in statistical control are recommended for estimating a process capability standard deviation. In that case, the number (*n*) of moving ranges averaged will be 29.

5.2.2 Calculate *Cp* and *Cpk* as shown in 6.3 and 6.4. The *Cp* index and the *Cpk* index must be greater than 1.00 in order to indicate the capability of the process to meet the established specifications. The *Cpk* index is inherently less than or equal to the *Cp* index (for one-sided specifications, only the *Cpk* index is applicable).

5.2.3 The *Cp* index indicates whether or not the process is capable of meeting a specification. Maximum performance is achieved when the process is perfectly centered and the *Cpk* is equal to the *Cp*.

5.2.4 In comparing one manufacturing unit to another, the larger *Cpk* index demonstrates a greater capability to conform to the specification range of the specified property.

5.2.5 *A process capability summary* can be used to evaluate a production unit over a period of time such as weekly, monthly, or quarterly. (See Fig. 1.) After each production run, or after 30 or so tests, the values of *n*, $\bar{x}$, ± difference from target, *MR*, 3$\hat{\sigma}$, *Cp*, and *Cpk* are recorded on the summary form. At the conclusion of the appropriate time interval, the grand average ($\bar{\bar{x}}$), average difference from target, average *Cp*, and average *Cpk* can be displayed at the foot of the appropriate column. These average values, especially the *Cpk*, can be used to compare the quality levels of different manufacturing units.

5.3 *Process Performance:*

5.3.1 A minimum of 30 test data are required, without regard to the process being in a state of statistical control, when calculating the standard deviation for process performance. In this case, extended production periods such as weeks or months can be represented.

5.3.2 Calculate *Pp* and *Ppk* as shown in 6.5 and 6.6. Both the *Pp* index and *Ppk* index must be greater than 1.0 in order to indicate that the process meets specifications. The *Ppk* index is inherently less than or equal to the *Pp* index (for one-sided specifications, only the *Ppk* is applicable).

5.3.3 A *process performance summary* can be used to summarize the data generated by the different production periods represented in a row of calculated values. (See Fig. 2.)

6. Calculation

6.1 Calculate estimated standard deviation ($\hat{\sigma}$) as follows:

$$(\hat{\sigma}) = \frac{R}{d_2} \quad (1)$$

where:

d_2 = 1.128 for $n = 2$.

6.2 Calculate sample standard deviation as follows:

$$s = \sqrt{\frac{\sum_{i=1}^{n} (X_i^{\,2}) - \bar{X}\left(\sum_{i=1}^{n} X_i\right)}{n-1}} \quad (2)$$

where:

s = sample standard deviation,
n = number of tests,
X_i = individual test results, and
$\bar{X}$ = average of all test results.

6.3 Calculate the *Cp* index as follows:

$$Cp \text{ index} = \frac{USL - LSL}{6\hat{\sigma}} \quad (3)$$

where:

USL = the upper specification limit,
LSL = the lower specification limit, and
$\hat{\sigma}$ = the process capability estimated standard deviation.

6.4 Calculate the *Cpk* index as follows:

$$Cpk \text{ index} = \text{minimum ratio of:} \quad (4)$$

$$\frac{USL - \bar{X}}{3\hat{\sigma}} \text{ or } \frac{\bar{X} - LSL}{3\hat{\sigma}} \quad (5)$$

PROCESS CAPABILITY SUMMARY

PLANT: ______________ UNIT: ______ GRADE: __________ PROPERTY: __________ AS OF DATE: _________

MATERIAL SPEC: ___________________

RANGE: ___________________

TARGET: ___________________

Production Period	n	$\bar{X}$	Difference +/− Target	$\overline{MR}$	3 σ	Cp	Cpk

FIG. 1 Sample Process Capability Summary Sheet

PROCESS PERFORMANCE SUMMARY

PLANT: ________ UNIT: ________ GRADE: ________ PROPERTY: ________ AS OF DATE: ________

MATERIAL SPEC: ________

RANGE: ________

TARGET: ________

Production Period	n	$\bar{X}$	Difference ± Target	3s	Pp	Ppk

FIG. 2 Sample Process Performance Summary Sheet

where:

$\bar{X}$ = the process average, and
$\hat{\sigma}$ = the estimated standard deviation.

6.5 Calculate the *Pp* index as follows:

$$Pp \text{ index} = \frac{USL - LSL}{6s} \quad (6)$$

6.6 Calculate the *Ppk* index as follows:

$$Ppk \text{ index} = \text{minimum ratio of:} \quad (7)$$

$$\frac{USL - \bar{X}}{3s} \text{ or } \frac{\bar{X} - LSL}{3s} \quad (8)$$

where:

$\bar{X}$ = the process average, and
s = the sample standard deviation.