HANSHO TECHNOLOGY BULLETIN

COMPOSITE CYLINDER DESIGN WITH STATISTICS TOOLS

Composite cylinder design engineers face common problems:

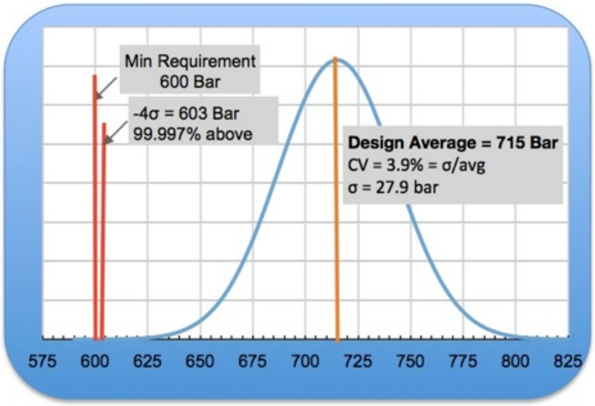
- Are the burst pressures high enough?
- Will the cylinders always pass burst testing when we start production?
- Is the cylinder design too strong and too expensive?
- Can we reduce the cost?
- How can I know these answers before we start production?

Statistical Design Tools provide the most reliable answers to these questions.

The best design is one that meets your goals for reliably passing burst test requirements without unnecessary additional strength and cost.

With statistics you can calculate this quickly

- -4 sigma design, 99.997% reliability
- -3 sigma design, 99.87% reliability
- Calculating it is simple with good test data.



4 Step Method to Statistical Design

With a simple, 4 Step Statistical Design Method, reliable low cost cylinders can be produced.

1. **Perform fiber strength testing** on a standard wrap pattern to gather fiber strengths and statistical data.
2. **Design cylinders for proper -4 sigma or -3 sigma strength.** Use the fiber strengths and statistics gathered from the first testing.
3. **Perform cylinder burst testing**; gather the actual testing data and statistics. Compare to step 2. Adjust the design if needed.
4. **Continue monitoring batch burst tests during production**. Keep monitoring the burst tests, averages, and other statistical data. Make sure your processes stay in control.

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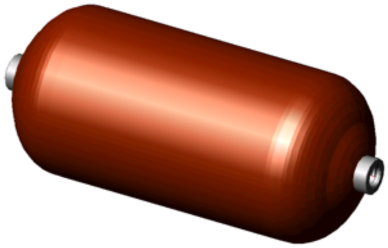
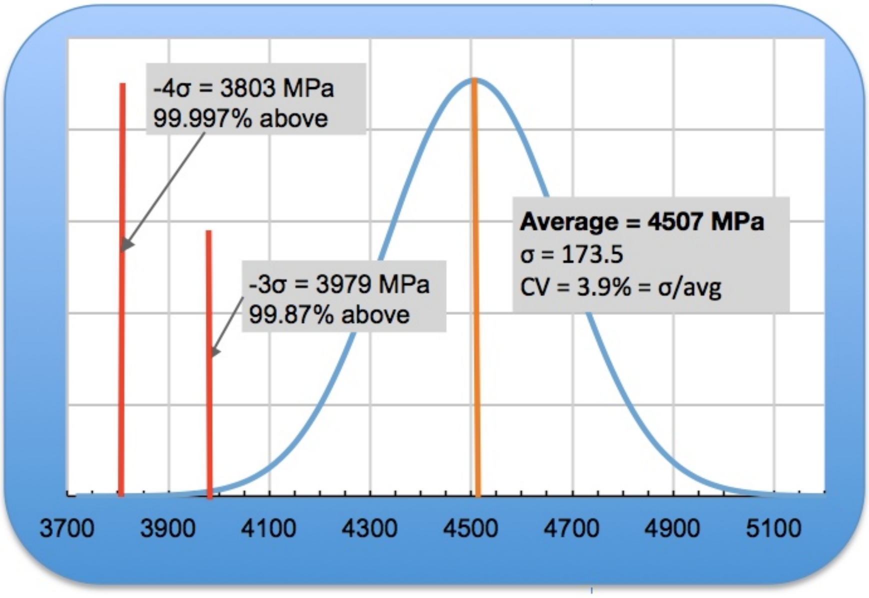
Step 1: Fiber Strength Burst Testing

1. Build cylinders with a standardized wrap pattern. This is often called a STEB: Standard Test and Evaluation Bottle.
2. Burst test the cylinders.
3. Calculate the fiber strength from each burst test.
    a. Calculated from FEA
    b. Measured by strain gages
4. Summarize with statistics.
5. Important factors:
    a. Average
    b. Sigma: Standard Deviation
    c. -3 Sigma value
    d. -4 Sigma value



Burst Test Number	Fiber Strengths, Mpa
1	4500
2	4700
3	4300
4	4500
5	4650
6	4300
7	4450
8	4700
9	4290
10	4318
11	4700
12	4680
13	4500
14	4720
15	4320
16	4480
17	4730
18	4290
Xbar = average:	4507
Std Deviation	173.5
CV%	3.9%
-3 sigma	3987
-4 sigma	3813

Standard Distribution of Fiber Strengths from Burst Testing



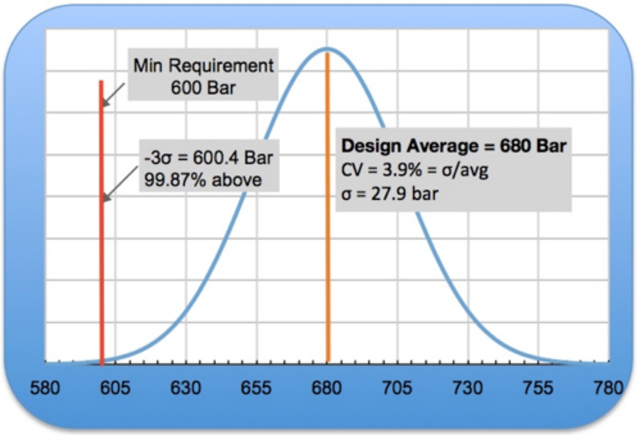
For cylinder design, use the AVERAGE, CV%, -3 SIGMA, and -4 SIGMA strength values determined through this testing.

Step 2: Design Cylinders using the fiber strength statistics

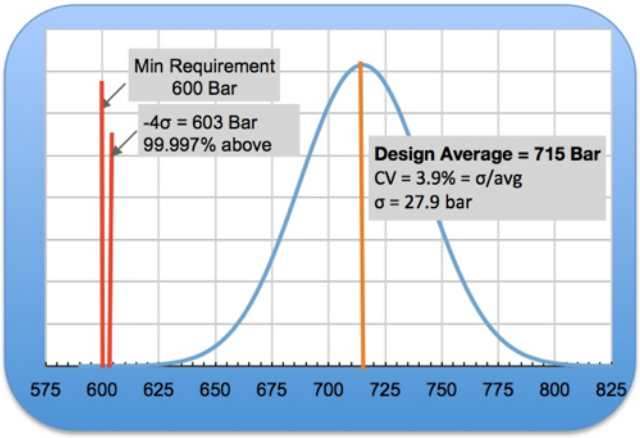
1. Use FEA, netting, and/or classical lamination theory calculations to determine the composite thicknesses and wrap pattern for the cylinder.
    a. FEA is more accurate to predict maximum fiber stress and location.
    b. Netting and classical lamination theories usually predict median fiber stress through the thickness.
2. Use the fiber strength statistics for the allowable strength values.
    a. Average fiber strength for average burst strength.
    b. Assume that C.V. (sigma/average) determined from fiber strength will be same for burst strengths.
    - In this example: CV = 3.9% for both fiber strength and burst strength design.
    c. From these data, it is simple to calculate -3 sigma and -4 sigma burst strengths.
3. Create a cylinder design based on either -3 sigma or -4 sigma burst strength must exceed minimum required burst strength.

For example: a 200 bar cylinder designed per ISO11119-3 must have a burst strength of 600 bar. The cylinders must always exceed the 600 bar burst strength. To design accordingly:

-3 Sigma Cylinder Design:
Average Burst Pressure = 680 bar
99.87% reliability



-4 Sigma Cylinder Design:
Average Burst Pressure = 715 bar
99.997% reliability



Many design engineers use -3 Sigma criterion for 99.87% reliability. The resulting burst pressure of 680 bar is 5% lower strength and less expensive than the 715 bar burst pressure for the -4 Sigma criterion for 99.997% reliability.

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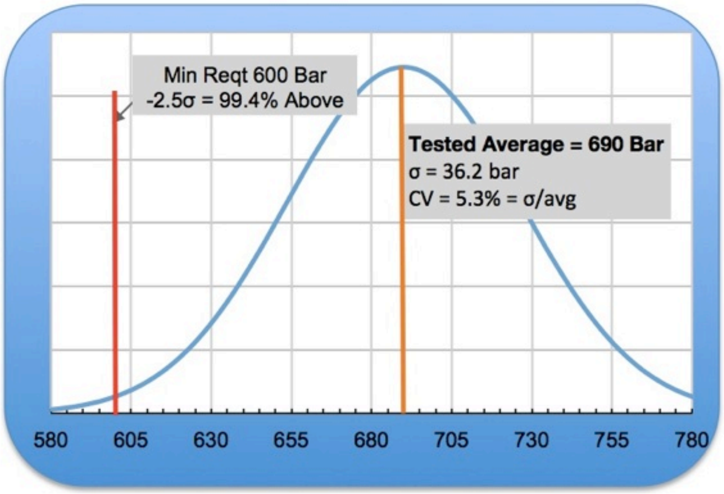
Step 3: Burst the prototype cylinders and confirm the design.

1. Build prototype cylinders, burst them, and collect the burst test data.
2. Perform statistical analysis.
3. Adjust the design thicknesses up or down as needed.
4. If not reliable enough, add thickness.
5. If too strong, reduce thickness and cost.

Example: Burst test program of 18 prototype cylinders, based on -3 sigma design from step 2.



Burst Test Number	Cylinder Burst Strength, bar
1	690
2	640
3	725
4	680
5	640
6	695
7	760
8	750
9	700
10	680
11	670
12	650
13	730
14	650
15	680
16	723
17	660
18	690
Xbar = average:	690
Std Deviation	36.2
CV% (Sigma/Avg)	5.3%
Maximum	760
Minimum	640
-3 sigma	581
-4 sigma	545

Conclusions from the testing:

- Average = 690 bar, target was 680. GOOD
- Std. Deviation =36.2 bar, Target was 27.9.
- **-3 Sigma Burst = 581 bar, Target was 600 bar.**
- Min Required Burst = 600 bar, -2.5 sigma level
- **Reliability to pass testing: 99.4%**

This is probably OK. It might be a good assumption that quality will improve when production is underway. Therefore the standard deviation will reduce. -3 sigma will increase.

Cylinder design is OK as is? Keep monitoring it during production.

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Step 4: Continue monitoring batch burst tests during production.

1. Perform burst testing of 1 cylinder per each batch of 200 cylinders (max).
2. Add each burst test and calculated fiber strengths into the data base.
3. Perform continuing statistical analysis.
4. Adjust the design or processes as needed.
5. **Factors to examine:**
   - Ensure the design always has > 99.9% probability to pass the tests.
   - Average and CV% remains constant each month and year
   - If average increases, investigate why. Reinforce the good effect.
   - If CV% decreases, investigate and reinforce.
   - If the -3 sigma (or -4 sigma) are too high, consider reducing material and cost.
   - If the -3 sigma (or -4 sigma) are too low, consider adding material or changing processes to increase them to acceptable level.

With good Statistical Design Tools, you can design cylinders efficiently, reliability, at lowest cost.
And you can control your factory production with highest reliability and efficiency.

Want to learn more?

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