2022 KEPIC Week 제주 라마다프라자 호텔

KEPIC(ASME BPVC)에서의 설계계수(안전계수) 이해

Transparency

Excellence

Responsibility

Independence

한국원자력안전기술원 기계재료평가실

송태광

2022.07.14

국민에게 신뢰받는 안전 최우선의 KINS

한국원자력안전기술원
KOREA INSTITUTE OF NUCLEAR SAFETY

KINS is a Cornerstone for a Safe Korea

Example of Design Report

Stresses

[Unit: MPa]

Item	Load Condition	Location	Code Criterion	Stress Intensity	Allowable
[redacted] Piping	Design	[redacted]	Stress Intensity	65	142.5
	Level A/B		Stress Range	360.53 1)	297
	Level D		Stress Intensity	219	220
[redacted] Branch	Design		P_L	93.89	196.5
	Level A/B		$P_L+P_B+P_e+Q$	574.61 1)	405
	Level D		P_m	200	287
			P_L+P_B	417	430
[redacted] Flange	Design Condition		Longitudinal Hub Stress	104	172.5
	Level A/B		Stress Range	483.92 1)	384
[redacted] Flange	Level A/B		Mean Stress	355	506
			Max. Stress	463	759
			Mean Stress	269	506
	Level D		Stress Intensity	112	700
			Mean Stress	79	700

Note 1) Simplified Elastic-Plastic Analysis according to NB-3228.5 is performed and satisfied.

“안전계수”하면 생각나는 것들

4.0

Safety factor

3.0

Safety margin

3.5

Design factor

안전계수

2.4

설계계수

Contents

KINS is a Cornerstone for a Safe Korea

KINS

1. KEPIC (ASME BPVC)에서의 안전계수는 몇인가?

- 코드 어디에 안전계수가 제시되어 있는가?

2. 안전계수가 높으면 더 안전하다고 할 수 있는가?

- “안전계수”는 올바른 표현인가?

3.0 (Class 1)	vs.	3.5 (Class 2 & 3)
Safety Factor	vs.	Design Factor

More safe ?

3. 안전계수의 근거는 무엇인가?

- 안전계수 변경의 정당성은?

KINS is a Cornerstone for a Safe Korea

<table>
<tr><th rowspan="2">ASME BPVC Edition or Year</th><th colspan="4">Design Factor</th></tr>
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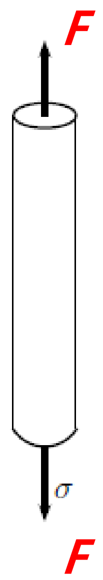
</table>

Failure Criteria for General Stress States

- **General Failure Criteria**

Applied Stress σ_{ij}	vs.	Material Resistance R_{mat} (i.e. S_Y, S_T)

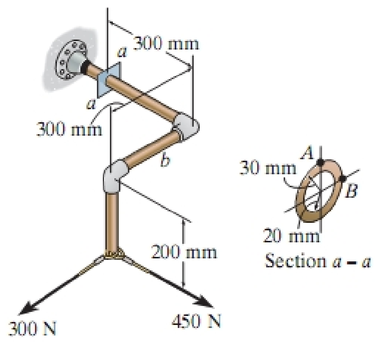
- **Uni-axial stress response of materials**
  - Simple : (σ_{11}) vs. (S_Y or S_T)

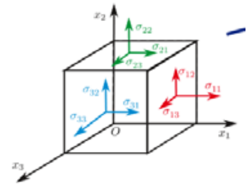


Failure Criteria for General Stress States

- **Multi-axial stress states**

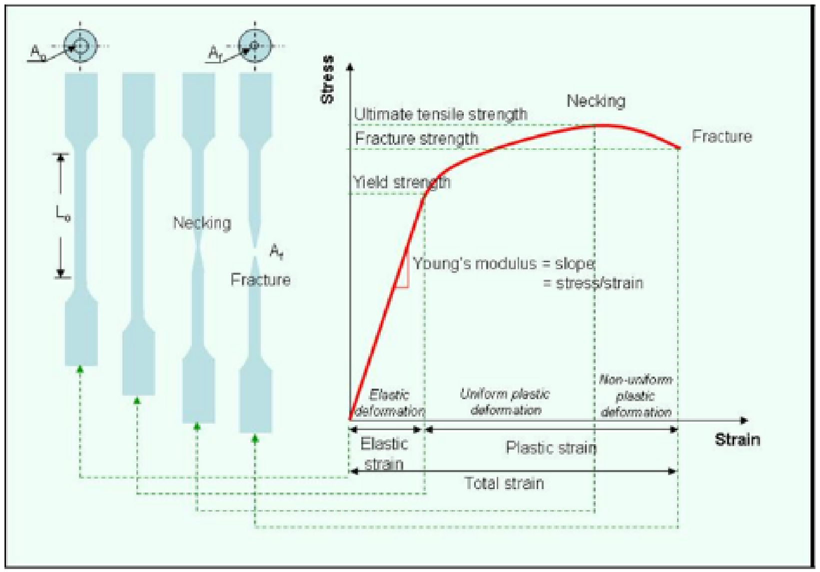
$$\begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{pmatrix} \rightarrow \boxed{?}$$





  - Various failure criteria has been derived

- **Uncertainty in Material Property**
  - Margin for material property, e.g.,
    S_Y or S_T or $2/3\ S_Y$ or $1/3\ S_T$ ··· ➔ ?



Safety Factor (Design Margin)

- **Applied stresses under internal pressure**

$$\sigma_{hoop} = \frac{P \cdot r}{t}$$

$$\sigma_{axial} = \frac{P \cdot r}{2t}$$

➔ $\sigma_{hoop} \le R_{mat}$

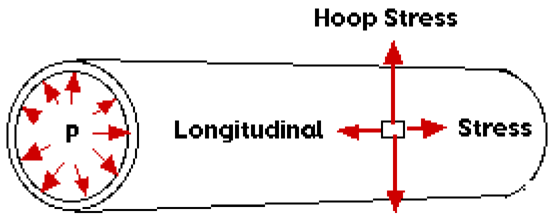


Fig. 6A- A long, cylindrical pipe is a thin-walled pressure vessel if the wall is thin with respect to the radius of the pipe. One can calulate that the hoop stress is twice as large as the longitudinal stress!

- **Safety Factor in ASME BPVC**

$$\sigma_{app} \le \frac{\sigma_T}{X}$$

  - X, divisor for tensile strength, is known as "safety factor"
  - Safety Factor is not explicitly defined in the Code

$\frac{\sigma_T}{X}$

- X=3.5 → S: Design Allowable Stress Value
- X=3.0 → S_m: Design Stress Intensity Value

Allowable Stress vs. Stress Intensity

- **Allowable Stress (허용응력)**
  - S
  - Sec. II, Part D, Table 1A, 1B

NC-3112.4 Design Allowable Stress Values.
(a) Allowable stresses for design for materials are listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, except for vessels designed to the requirements of NC-3200, for which the design stress intensity values are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The materials shall not be used at metal and design

NC-3640 PRESSURE DESIGN OF PIPING PRODUCTS

NC-3641 Straight Pipe

NC-3641.1 Straight Pipe Under Internal Pressure. The minimum thickness of pipe wall required for Design Pressures and for temperatures not exceeding those for the various materials listed in Section II, Part D, Subpart 1, Tables 1A, 1B, and 3, including allowances for mechanical strength, shall not be less than that determined by eq. (3) as follows:

$$t_m = \frac{PD_o}{2(S + Py)} + A \qquad (3)$$

$$t_m = \frac{Pd + 2SA + 2yPA}{2(S + Py - P)} \qquad (4)$$

S

NC-3652 Consideration of Design Conditions

The effects of pressure, weight, and other sustained mechanical loads must meet the requirements of eq. (8):

$$S_{SL} = B_1\frac{PD_o}{2t_n} + B_2\frac{M_A}{Z} \leq 1.5S_h \qquad (8)$$

- **Stress Intensity (응력강도)**
  - Sm
  - Sec. II, Part D, Tables 2A and 2B

NB-3112.4 Design Stress Intensity Values. Design stress intensity values for materials are listed in Section II, Part D, Subpart 1, Tables 2A, 2B, and 4. The material

NB-3640 PRESSURE DESIGN

NB-3641 Straight Pipe

NB-3641.1 Straight Pipe Under Internal Pressure. The minimum thickness of a pipe wall required for Design Pressure shall be determined from one of the following equations:

$$t_m = \frac{PD_o}{2(S_m + Py)} + A \qquad (1)$$

$$t_m = \frac{Pd + 2A(S_m + Py)}{2(S_m + Py - P)} \qquad (2)$$

S_m

NB-3652 Consideration of Design Conditions

The primary stress intensity limit is satisfied if the requirement of eq. (9) is met:

$$B_1\frac{PD_o}{2t} + B_2\frac{D_o}{2I}M_i \leq 1.5S_m \qquad (9)$$

Safety Factor in the Code

- **Sec. II, Mandatory App.1**
  - "Basis for Establishing Stress Values in Tables 1A and 1B"
  - $S = Min\left[\frac{S_T}{3.5}, {}^2/_3\, S_Y\right]$

- **Sec. II, Mandatory App.2**
  - "Basis for Establishing Design Stress Intensity Values For Tables 2A and 2B, and 4, And Allowable Stress Value for Table 3"
  - $S_m = Min\left[\frac{S_T}{3.0}, {}^2/_3\, S_Y\right]$

Historical Change of Design Margin

Table 1A, 1B → Sec. III, Class 2 & 3; Sec. VIII, Div.1

Table 2A, 2B → Sec. III, Class 1; Sec. VIII, Div.2 prior to 2007

Table 5A, 5B → Sec. VIII, Div.2 since 2007

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Sample Problem

- **내압 및 모멘트가 작용하는 SA-106 배관 설계 (Class 1 과 2 간략 비교)**

  - Class 2 배관 (NC-3652, Consideration of Design Conditions)

$$\boldsymbol{B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \leq 1.5S}$$

  - Class 1 배관 (NB-3652, Consideration of Design Conditions)

$$\boldsymbol{B_1 \frac{PD_o}{2t} + B_2 \frac{D_o}{2I} M_i \leq 1.5S_m}$$

Allowable Stress of SA-106 (1/2)

Table 1A

(17)

Table 1A
Section I; Section III, Classes 2 and 3;* Section VIII, Division 1; and Section XII
Maximum Allowable Stress Values *S* for Ferrous Materials
(*See Maximum Temperature Limits for Restrictions on Class)

Line No.	Nominal Composition	Product Form	Spec. No.	Type/Grade	Alloy Desig./UNS No.	Class/Condition/Temper	Size/Thickness, in.	P-No.	Group No.
1	Carbon steel	Sheet	SA-1008	CS-A	...	...	...	1	1
2	Carbon steel	Sheet	SA-1008	CS-B	...	...	...	1	1
3	Carbon steel	Bar	SA-675	45	...	...	...	1	1
4	Carbon steel	Wld. pipe	SA-134	A283A	...	...	...	1	1
5	Carbon steel	Plate	SA-283	A	...	...	...	1	1
6	Carbon steel	Plate	SA-285	A	K01700	...	...	1	1
7	Carbon steel	Wld. pipe	SA-672	A45	K01700	...	...	1	1
8	Carbon steel	Sheet	SA-414	A	K01501	...	...	1	1
9	Carbon steel	Wld. tube	SA-178	A	K01200	...	...	1	1
10	Carbon steel	Wld. tube	SA-178	A	K01200	...	...	1	1
11	Carbon steel	Smls. tube	SA-179	...	K01200	...	...	1	1
12	Carbon steel	Smls. tube	SA-192	...	K01201	...	...	1	1
13	Carbon steel	Wld. tube	SA-214	...	K01807	...	...	1	1
14	Carbon steel	Smls. tube	SA-556	A2	K01807	...	...	1	1
15	Carbon steel	Wld. tube	SA-557	A2	K01807	...	...	1	1
16	Carbon steel	Wld. pipe	SA-53	E/A	K02504	...	...	1	1
17	Carbon steel	Wld. pipe	SA-53	E/A	K02504	...	...	1	1
18	Carbon steel	Wld. pipe	SA-53	E/A	K02504	...	...	1	1
19	Carbon steel	Wld. pipe	SA-53	F/A	...	...	...	1	1
20	Carbon steel	Smls. pipe	SA-53	S/A	K02504	...	...	1	1
21	Carbon steel	Smls. pipe	SA-53	S/A	K02504	...	...	1	1
22	Carbon steel	Smls. pipe	SA-106	A	K02501	...	...	1	1
23	Carbon steel	Wld. pipe	SA-135	A	...	...	...	1	1
24	Carbon steel	Forged pipe	SA-369	FPA	K02501	...	...	1	1
25	Carbon steel	Wld. pipe	SA-587	...	K11500	...	...	1	1
26	Carbon steel	Wld. pipe	SA-587	...	K11500	...	...	1	1
27	Carbon steel	Bar	SA-675	50	...	...	...	1	1
28	Carbon steel	Bar	SA-675	50	...	...	...	1	1
29	Carbon steel	Wld. pipe	SA-134	A283B	...	...	...	1	1
30	Carbon steel	Plate	SA-283	B	...	...	...	1	1
31	Carbon steel	Plate	SA-285	B	K02200	...	...	1	1
32	Carbon steel	Plate	SA-285	B	K02200	...	...	1	1
33	Carbon steel	Wld. pipe	SA-672	A50	K02200	...	...	1	1
34	Carbon steel	Sheet	SA-414	B	K02201	...	...	1	1
35	Carbon steel	Plate	SA/EN 10028-3	P275NH	...	...	$6 < t \le 10$	1	1
36	Carbon steel	Plate	SA/EN 10028-2	P235GH	...	...	$\le 2^1/_4$	1	1
37	Carbon steel	Smls. tube	SA/EN 10216-2	P235GH	...	...	$1^5/_8 < t \le 2^1/_2$	1	1
38	Carbon steel	Plate	SA/EN 10028-3	P275NH	...	...	$4 < t \le 6$	1	1
39	Carbon steel	Smls. tube	SA/EN 10216-2	P235GH	...	...	$^5/_8 < t \le 1^5/_8$	1	1
40	Carbon steel	Smls. tube	SA/EN 10216-2	P235GH	...	...	$t \le {}^5/_8$	1	1
41	Carbon steel	Plate	SA/EN 10028-3	P275NH	...	...	$2^1/_4 < t \le 4$	1	1
42	Carbon steel	Bar	SA-675	55	...	...	...	1	1
43	Carbon steel	Bar	SA-675	55	...	...	...	1	1

Table 1A
Section I; Section III, Classes 2 and 3;* Section VIII, Division 1; and Section XII
Maximum Allowable Stress Values *S* for Ferrous Materials
(*See Maximum Temperature Limits for Restrictions on Class)

Line No.	Min. Tensile Strength, ksi	Min. Yield Strength, ksi	Applicability and Max. Temperature Limits (NP = Not Permitted) (SPT = Supports Only) I	III	VIII-1	XII	External Pressure Chart No.	Notes
1	40	20	NP	NP	650	NP	CS-6	...
2	40	20	NP	NP	650	NP	CS-6	...
3	45	22.5	NP	650 (Cl. 3 only)	900	650	CS-6	G10, G22, T10
4	45	24	NP	300 (Cl. 3 only)	NP	NP	CS-1	W12
5	45	24	NP	300 (Cl. 3 only)	650	650	CS-1	...
6	45	24	900	700	900	650	CS-1	G10, T2
7	45	24	NP	700	NP	NP	CS-1	S6, W10, W12
8	45	25	NP	NP	900	650	CS-1	G10, T2
9	47	26	1000	NP	NP	NP	CS-1	G4, G10, S1, T2, W13
10	47	26	1000	NP	1000	650	CS-1	G3, G10, G24, S1, T2, W6
11	47	26	NP	NP	900	650	CS-1	G10, T2
12	47	26	1000	NP	1000	650	CS-1	G10, S1, T2
13	47	26	NP	NP	1000	650	CS-1	G24, T2, W6
14	47	26	NP	NP	1000	650	CS-1	G10, T2
15	47	26	NP	NP	1000	650	CS-1	G24, T2, W6
16	48	30	900	NP	NP	NP	CS-2	G3, G10, S1, T2
17	48	30	900	300 (Cl. 3 only)	NP	NP	CS-2	G10, S1, T2, W12, W13
18	48	30	NP	NP	900	650	CS-2	G24, T2, W6
19	48	30	750	NP	NP	NP	CS-2	G2, G10, S10, T2, W15
20	48	30	900	300 (Cl. 3 only)	NP	NP	CS-2	G10, S1, T2
21	48	30	NP	700 (SPT)	900	650	CS-2	G10, T2
22	48	30	1000	700	1000	650	CS-2	G10, S1, T1
23	48	30	NP	NP	900	650	CS-2	G24, T2, W6
24	48	30	1000	NP	NP	NP	CS-2	G10, S1, T1
25	48	30	NP	300 (Cl. 3 only)	NP	NP	CS-2	...
26	48	30	NP	NP	850	650	CS-2	G24, T2, W6
27	50	25	NP	650 (Cl. 3 only)	NP	NP	CS-1	...
28	50	25	850	700 (SPT)	900	650	CS-1	G10, G15, G22, S1, T2
29	50	27	NP	300 (Cl. 3 only)	NP	NP	CS-1	W12
30	50	27	NP	300 (Cl. 3 only)	650	650	CS-1	...
31	50	27	900	NP	NP	NP	CS-1	G10, S1, T1
32	50	27	NP	700	900	650	CS-1	G10, T1
33	50	27	NP	700	NP	NP	CS-1	S6, T1, W10, W12
34	50	30	NP	NP	900	650	CS-2	G10, T1
35	51	31	NP	NP	400	NP	CS-2	G10
36	52	31	NP	NP	700	NP	CS-2	T11
37	52	31	1000	NP	1000	NP	CS-2	G10, S1, T2, W14
38	52	32.5	NP	NP	400	NP	CS-2	G10
39	52	32.5	1000	NP	1000	NP	CS-2	G10, S1, T2, W14
40	52	34	1000	NP	1000	NP	CS-2	G10, S1, T2, W14
41	53.5	34	NP	NP	400	NP	CS-2	G10
42	55	27.5	850	700 (SPT)	900	650	CS-1	G10, G15, G22, S1, T2
43	55	27.5	NP	650 (Cl. 3 only)	NP	NP	CS-1	...

$S_T = 48$ ksi $S_Y = 30$ ksi

Allowable Stress of SA-106 (2/2)

Maximum Allowable Stress

Table 1A
Section I; Section III, Classes 2 and 3;* Section VIII, Division 1; and Section XII
Maximum Allowable Stress Values *S* for Ferrous Materials
(*See Maximum Temperature Limits for Restrictions on Class)

Line No.	Maximum Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding: 100	150	200	250	300	400	500	600	650	700	750	800	850	900
1	11.4	11.4	11.4	...	11.4	11.4	10.9	10.2	9.9	...	...	...	...	...
2	11.4	11.4	11.4	...	11.4	11.4	10.9	10.2	9.9	...	...	...	...	...
3	12.9	12.9	12.9	...	12.9	12.8	12.2	11.5	11.1	10.7	10.4	9.2	7.9	5.9
4	12.9	...	12.9	...	12.9	...	...	...	...	...	...	...	...	...
5	12.9	12.9	12.9	...	12.9	12.9	12.9	12.3	11.9	...	...	...	...	...
6	12.9	12.9	12.9	...	12.9	12.9	12.9	12.3	11.9	11.5	10.7	9.2	7.9	5.9
7	12.9	...	12.9	...	12.9	12.9	12.9	12.3	11.9	11.5	...	...	...	...
8	12.9	12.9	12.9	...	12.9	12.9	12.9	12.8	12.4	11.9	10.7	9.2	7.9	5.9
9	13.4	...	13.4	...	13.4	13.4	13.4	13.3	12.8	12.4	10.7	9.2	7.9	5.9
10	11.4	11.4	11.4	...	11.4	11.4	11.4	11.3	10.9	10.5	9.1	7.8	6.7	5.0
11	13.4	13.4	13.4	...	13.4	13.4	13.4	13.3	12.8	12.4	10.7	9.2	7.9	5.9
12	13.4	13.4	13.4	...	13.4	13.4	13.4	13.3	12.8	12.4	10.7	9.2	7.9	5.9
13	11.4	11.4	11.4	...	11.4	11.4	11.4	11.3	10.9	10.5	9.1	7.8	6.7	5.0
14	13.4	13.4	13.4	...	13.4	13.4	13.4	13.3	12.8	12.4	10.7	9.2	7.9	5.9
15	11.4	11.4	11.4	...	11.4	11.4	11.4	11.3	10.9	10.5	9.1	7.8	6.7	5.0
16	11.7	...	11.7	...	11.7	11.7	11.7	11.7	11.7	10.6	9.1	7.7	6.1	4.3
17	13.7	...	13.7	...	13.7	13.7	13.7	13.7	13.7	12.5	10.7	9.0	7.1	5.0
18	11.7	11.7	11.7	...	11.7	11.7	11.7	11.7	11.7	10.6	9.1	7.9	6.7	5.5
19	8.2	...	8.2	...	8.2	8.2	8.2	8.2	8.2	7.5	6.4	...	...	...
20	13.7	...	13.7	...	13.7	13.7	13.7	13.7	13.7	12.5	10.7	9.0	7.1	5.0
21	13.7	13.7	13.7	...	13.7	13.7	13.7	13.7	13.7	12.5	10.7	9.3	7.9	6.5
22	13.7	13.7	13.7	...	13.7	13.7	13.7	13.7	13.7	12.5	10.7	9.3	7.9	6.5
23	11.7	11.7	11.7	...	11.7	11.7	11.7	11.7	11.7	10.6	9.1	7.9	6.7	5.5
24	13.7	...	13.7	...	13.7	13.7	13.7	13.7	13.7	12.5	10.7	9.0	7.1	5.0
25	13.7	...	13.7	...	13.7	...	...	...	...	...	...	...	...	...
26	11.7	11.7	11.7	...	11.7	11.7	11.7	11.7	11.7	10.6	9.1	7.9	6.7	...
27	14.3	...	14.3	...	14.3	14.2	13.6	12.8	12.4	...	...	...	...	...
28	14.3	14.3	14.3	...	14.3	14.2	13.6	12.8	12.4	11.9	10.7	9.3	7.9	6.5
29	14.3	...	14.3	...	14.3	...	...	...	...	...	...	...	...	...
30	14.3	14.3	14.3	...	14.3	14.3	14.3	13.8	13.3	...	...	...	...	...
31	14.3	...	14.3	...	14.3	14.3	14.3	13.8	13.3	12.5	11.0	9.4	7.3	5.0
32	14.3	14.3	14.3	...	14.3	14.3	14.3	13.8	13.3	12.5	11.2	9.6	8.1	5.9
33	14.3	...	14.3	...	14.3	14.3	14.3	13.8	13.3	12.5	...	...	...	...
34	14.3	14.3	14.3	...	14.3	14.3	14.3	14.3	14.3	12.5	11.2	9.6	8.1	5.9
35	14.5	14.5	14.5	...	14.5	14.5	...	...	...	...	...	...	...	...
36	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.9	14.6	12.5	...	...	...	...
37	14.9	...	14.9	...	14.9	14.9	14.9	14.9	14.9	14.9	13.0	10.8	8.7	5.9
38	14.9	14.9	14.9	...	14.9	14.9	...	...	...	...	...	...	...	...
39	14.9	...	14.9	...	14.9	14.9	14.9	14.9	14.9	14.9	13.0	10.8	8.7	5.9
40	14.9	...	14.9	...	14.9	14.9	14.9	14.9	14.9	14.9	13.0	10.8	8.7	5.9
41	15.3	15.3	15.3	...	15.3	15.3	...	...	...	...	...	...	...	...
42	15.7	15.7	15.7	...	15.7	15.7	14.9	14.1	13.6	13.1	12.7	10.8	8.7	5.9
43	15.7	...	15.7	...	15.7	15.7	14.9	14.1	13.6	...	...	...	...	...

S= 13.7 ksi

Basis?

Table 1A
Section I; Section III, Classes 2 and 3;* Section VIII, Division 1; and Section XII
Maximum Allowable Stress Values *S* for Ferrous Materials
(*See Maximum Temperature Limits for Restrictions on Class)

Line No.	Maximum Allowable Stress, ksi (Multiply by 1000 to Obtain psi), for Metal Temperature, °F, Not Exceeding: 950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450	1500	1550	1600	1650
1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
6	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
9	4.0	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
10	3.4	2.1	...	...	...	...	...	...	...	...	...	...	...	...	...
11	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
12	4.0	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
13	3.4	2.1	...	...	...	...	...	...	...	...	...	...	...	...	...
14	4.0	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
15	3.4	2.1	...	...	...	...	...	...	...	...	...	...	...	...	...
16	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
17	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
18	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
19	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
20	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
21	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
22	4.5	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
23	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
24	3.0	1.5	...	...	...	...	...	...	...	...	...	...	...	...	...
25	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
26	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
27	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
28	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
29	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
30	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
31	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
32	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
33	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
34	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
35	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
36	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
37	4.0	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
38	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
39	4.0	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
40	4.0	2.5	...	...	...	...	...	...	...	...	...	...	...	...	...
41	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
42	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
43	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

Allowable Stress and Stress Intensity of SA-106

- **Allowable Stress of SA-106 (Class 2)**

  - $S = Min\left[\frac{S_T}{3.5}, {}^2/_3\, S_Y\right]$ with S_T=48 ksi and S_Y=30 ksi

    = $Min\,[13.7\,ksi, 20.0\,ksi]$

    = 13.7 ksi

- **Stress Intensity of SA-106 (Class 1)**

  - $S_m = Min\left[\frac{S_T}{3.0}, {}^2/_3\, S_Y\right]$ with S_T=48 ksi and S_Y=30 ksi

    = $Min\,[16.0 ksi, 20.0\,ksi]$

    = 16.0 ksi

For comparison…

- **Allowable Stress of SA-312 TP304 (Class 2)**
  - $S = Min\left[\frac{S_T}{3.5}, {}^2/_3\, S_Y\right]$ with S_T=70 ksi and S_Y=25 ksi

    $= Min\,[20\,ksi, 16.7\,ksi]$

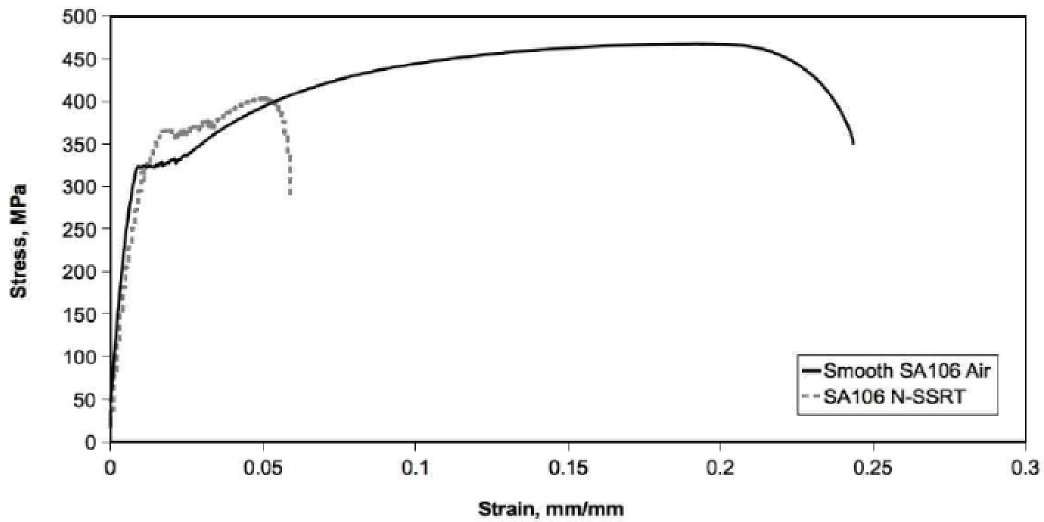
    = 16.7 ksi

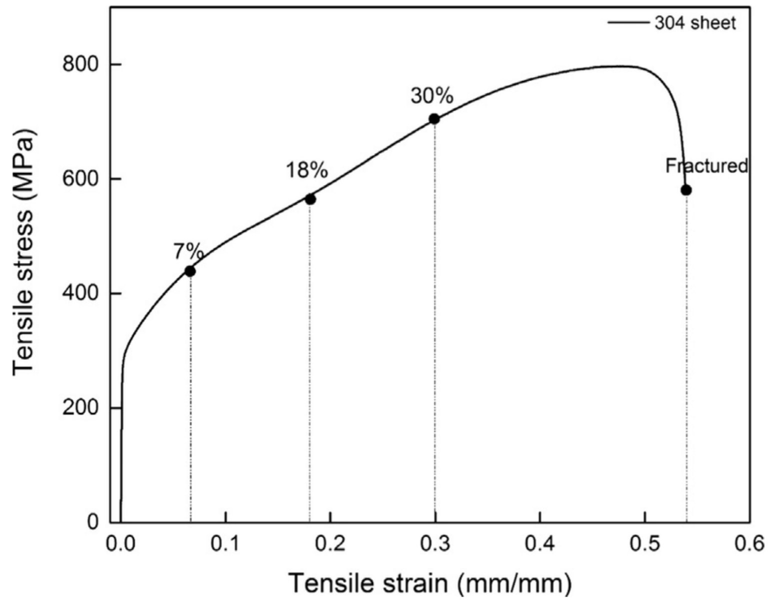
- **Stress Intensity of SA-312 TP304 (Class 1)**
  - $S_m = Min\left[\frac{S_T}{3.0}, {}^2/_3\, S_Y\right]$ with with S_T=70 ksi and S_Y=25 ksi

    $= Min\,[23.3\,ksi, 16.7\,ksi]$

    = 16.7 ksi

Material Properties





SA-106 vs. SA-312 TP304

Interim remark

“안전계수”란...

- “안전계수” 용어 정의는 코드에 명시되어 있지 않지만,

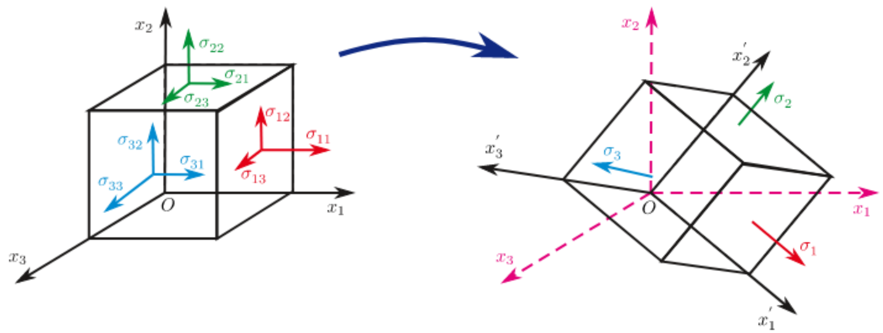
- 통상 허용응력(Class 2, 3) 또는 응력강도(Class 1) 산출 시 인장강도를 나누는 계수로 알려져 있다.

- 동일한 재료라도 재료가 사용되는 분야(service area 또는 ASME Section)에 따라, Code 년판 등에 따라 안전계수는 달라진다.

Failure Criteria

- Principle Stress

$$\begin{pmatrix} \sigma_{11} & \sigma_{12} & \sigma_{13} \\ \sigma_{21} & \sigma_{22} & \sigma_{23} \\ \sigma_{31} & \sigma_{32} & \sigma_{33} \end{pmatrix} \rightarrow \begin{pmatrix} \sigma_1 & 0 & 0 \\ 0 & \sigma_2 & 0 \\ 0 & 0 & \sigma_3 \end{pmatrix}$$



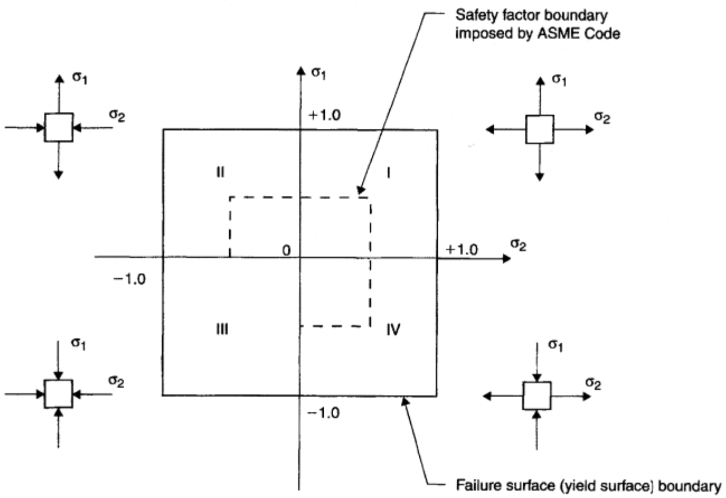
- Maximum Principle Stress Theory (최대주응력 이론)
- Maximum Shear Stress Theory (최대전단응력 이론)
- Maximum Distortion Energy Theory (최대변형에너지 이론)

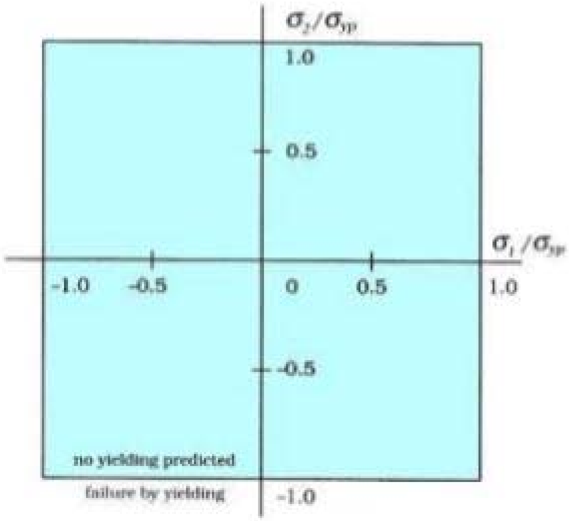
Maximum Principle Stress Theory (최대주응력 이론)

- Failure is expected when the largest principal normal stress reaches the uniaxial yield strength of the material(σ_y)
- Failure occurs when

  Max $[|\sigma_1|, |\sigma_2|, |\sigma_3|] = \sigma_y$

- Perhaps the simplest failure criterion
- Great success for predicting failure of brittle materials





Maximum Shear Stress Theory (최대변형응력 이론)

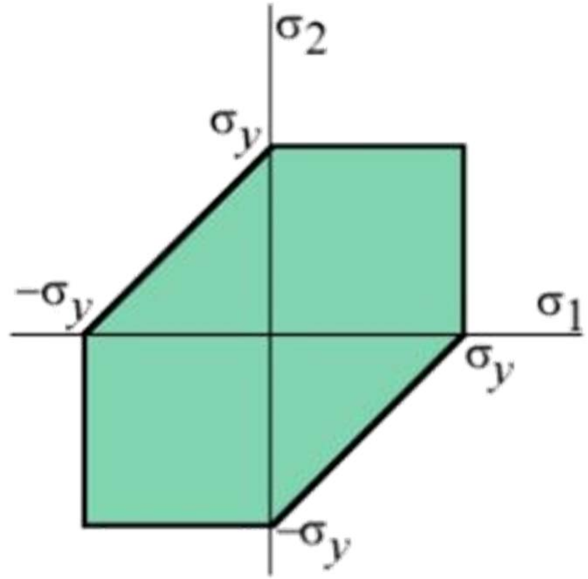
- failure is expected when the maximum shear stress reaches the yield stress in shear (τ_0)
- often called the Tresca criteria
- Failure occurs when

$$\text{Max}\ [\frac{|\sigma_1-\sigma_2|}{2},\frac{|\sigma_2-\sigma_3|}{2},\frac{|\sigma_3-\sigma_1|}{2}] = \tau_0$$

$$\rightarrow \text{Max}\ [\frac{|\sigma_1-\sigma_2|}{2},\frac{|\sigma_2-\sigma_3|}{2},\frac{|\sigma_3-\sigma_1|}{2}] = \frac{\sigma_y}{2}$$

or

$$\text{Max}\ [|\sigma_1-\sigma_2|, |\sigma_2-\sigma_3|, |\sigma_3-\sigma_1|] = \sigma_y$$



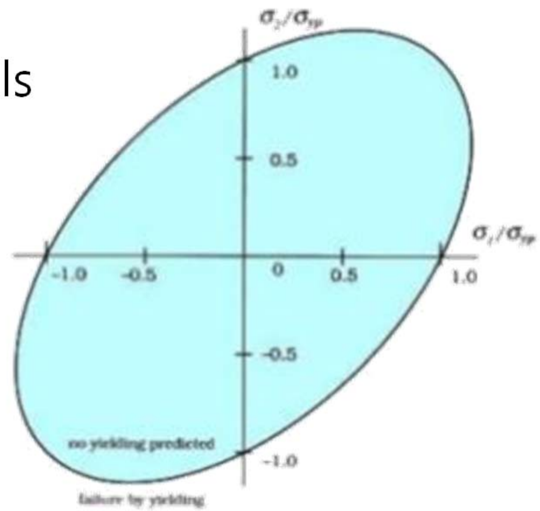
- Great success for predicting failure of ductile materials

Maximum Distortion Energy Theory (최대변형에너지 이론)

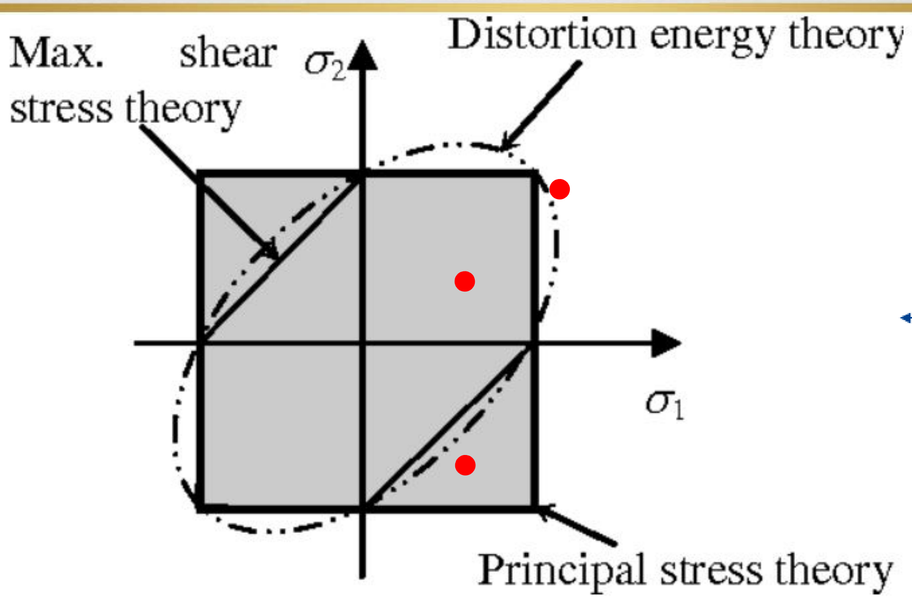
- Failure is expected when the maximum distortion energy per unit volume reaches the uniaxial yield strength of the material(σ_y)
- Often called the Von Mises criteria
- Failure occurs when

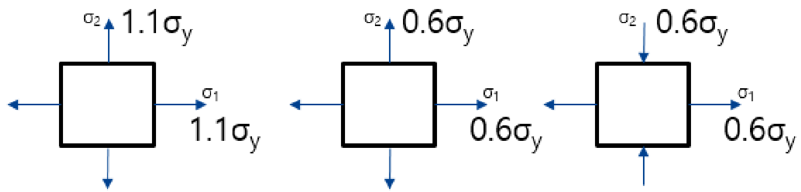
$$\sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_2)^2+(\sigma_1-\sigma_2)^2}{2}}=\sigma_y$$

- Great success for predicting failure of ductile materials



Comparison of Failure Criteria





최대주응력이론 vs. 최대변형응력이론

- 최대주응력이론이 단순하고 직관적이나,
- 전단변형이 작용하는 경우(특히, 주응력의 방향이 반대인 경우) 부정확(비보수적) 할 수 있다.

최대변형응력이론 vs. 최대변형에너지이론

- 최대변형응력이론은 상대적으로 단순하며, 최대변형에너지이론 대비 결과의 차이가 크지 않다.(15% 내외)

Basis of Safety Factor

Maximum Principal Stress Theory

- 단순하지만 부정확할 수 있다
- 상대적으로 높은 안전계수 3.5 적용
- Sec. III, Div.1, Class 2,3 ; Sec. VIII, Div. 1

Maximum Shear Stress Theory

- 상대적으로 단순하며 정확하다
- 상대적으로 낮은 안전계수 3.0 적용
- Sec. III, Div.1, Class 1 ; Sec. VIII, Div.2(2007년 이전)

Maximum Distortion Energy Theory

- 정확하다
- 상대적으로 가장 낮은 안전계수 2.4 적용
- Sec. VIII, Div. 2 (2007년 이후)

Comprehensive basis of Safety Factor

- Tresca criteria
- Fracture Toughness
- Fatigue Evaluation
- Extensive NDE

- Improvements in the Code that have been added since the 1960s
- Competition with other Codes

- Von Mises Criteria
- Extensive NDE

<table>
<tr><th rowspan="2">ASME BPVC Edition or Year</th><th colspan="4">Design Factor</th></tr>
<tr><th>Sec. III, Class 2 & 3; Sec. VIII, Div.1</th><th>Sec. III, Class 1; Sec. VIII, Div.2 prior to 2007</th><th>Sec. VIII, Div.2 since 2007</th><th>B31.1</th></tr>
<tr><td>1915</td><td rowspan="2">5.0</td><td></td><td></td><td></td></tr>
<tr><td>1935</td><td></td><td></td><td>?</td></tr>
<tr><td>WWII</td><td rowspan="5">4.0</td><td></td><td></td><td></td></tr>
<tr><td>1963</td><td rowspan="10">3.0</td><td></td><td></td></tr>
<tr><td>1968</td><td></td><td></td></tr>
<tr><td>1971</td><td></td><td></td></tr>
<tr><td>1998</td><td></td><td></td></tr>
<tr><td>1999 Add</td><td rowspan="6">3.5</td><td></td><td></td></tr>
<tr><td>2004</td><td></td><td>4.0</td></tr>
<tr><td>2005 Add</td><td></td><td>3.5</td></tr>
<tr><td>2007</td><td rowspan="3">2.4</td><td></td></tr>
<tr><td>2010</td><td></td></tr>
<tr><td>2015</td><td></td></tr>
</table>

Safety Factor vs. Design Factor

Question

- **Class 2 piping is more safe than Class 1 piping ?**
- **ASME Section III is more safe than Section VIII ?**

Design Factor

- The design factor used by the ASME Committee to determine allow able stress has sometimes been referred to as a safety factor. How ever, the term safety factor is both incorrect and misleading, becaus e a reduction in the factor would seem to indicate a reduction in sa fety. In fact, when the Code Committee has considered a reduction in design factor, it has been allowed only after the Code Committee determines that other changes to Code requirements have **compen sated** for the reduction.

Trade-Off Concept in Design Factor

- Stress Theories
- Fatigue analysis
- NDE
- Fracture toughness
- Material quality
- Experience

Design Factor

Trade-Off

with maintaining the same level of safety

Concluding Remarks

Design Factor

- is intended to account for unknowns in design and construction

Design Factor

- is different depending on each Code Section and Division

Level of Safety

- ASME Code maintains the same level of safety regardless of each Section and Division.
- The different Code Sections and Divisions address service applications, not different levels of safety

Reference

- Becht Engineering 社 홈페이지, article “Nuclear Piping Design Margins – A Brief History”
- ASME Sec. II, Mandatory Appendix 1, “Basis for establishing stress values in Tables 1A and 1B”, 2015 Ed.
- ASME Sec. II, Mandatory Appendix 2, “Basis for establishing design stress intensity values for Tables 2A 2B, and 4, and allowable stress values for Table 3”, 2015 Ed.
- Sperko Engineering 社 홈페이지, article “Reduction of Design Margin(”Safety Factor“) in the ASME Boiler and Pressure Vessel Code in the 1999 Addenda”
- NUREG-1367, “Functional Capability of Piping Systems”, US NRC, 1992.
- Companion Guide to ASME BPVC,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