8강 유동응력과 마찰

8강 목차

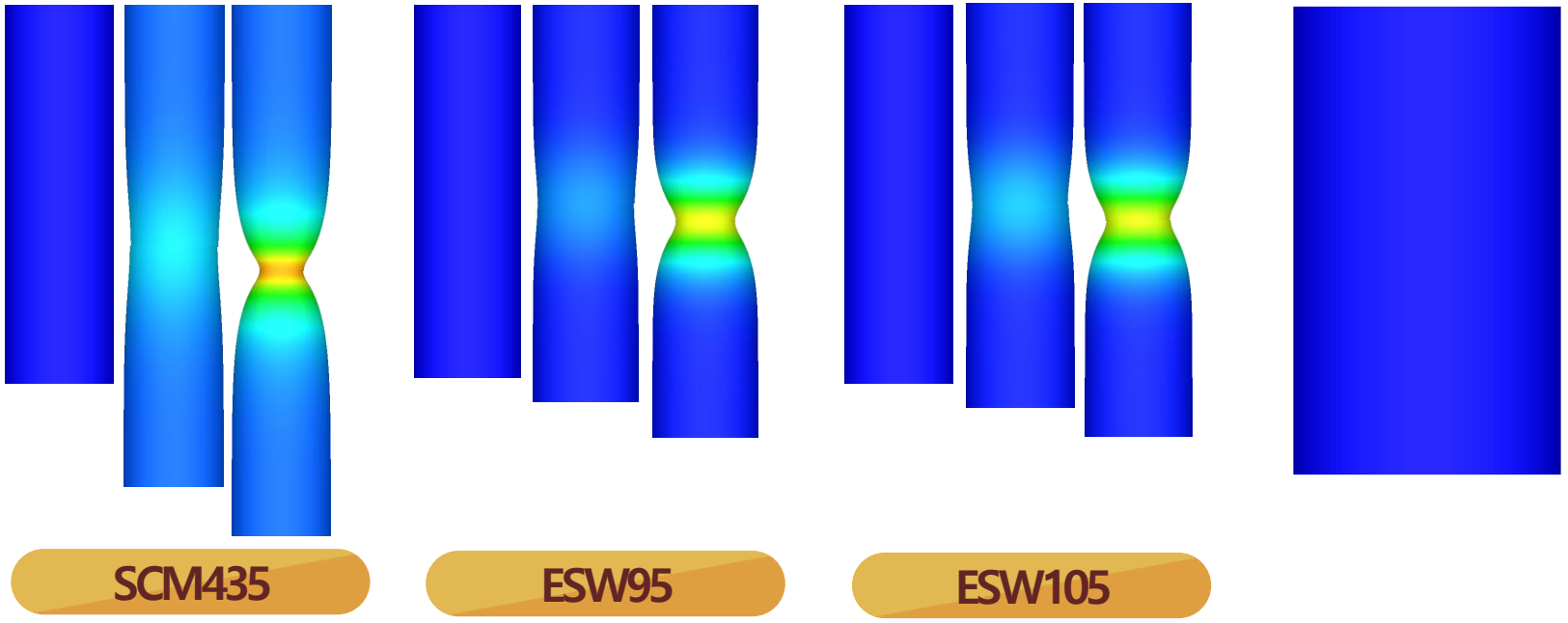
8.1 상온 유동응력 획득 및 Bauschinger 효과

8.2 고온 유동응력 획득

8.3 마찰, 윤활, 마모

1. 상온 유동응력 획득 및 Bauschinger 효과

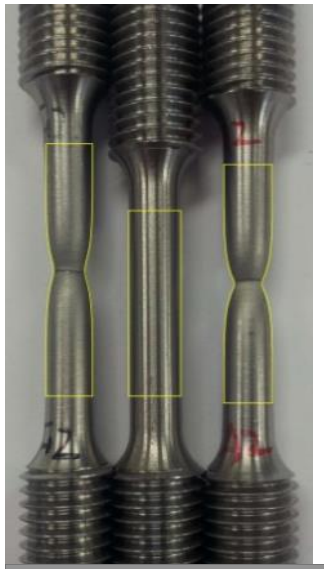
상온상태에서의 인장시험

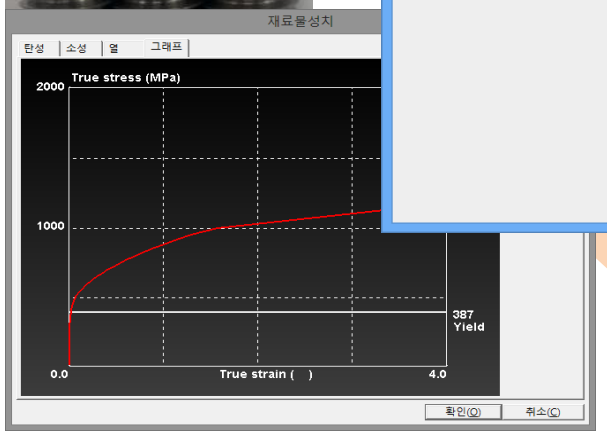


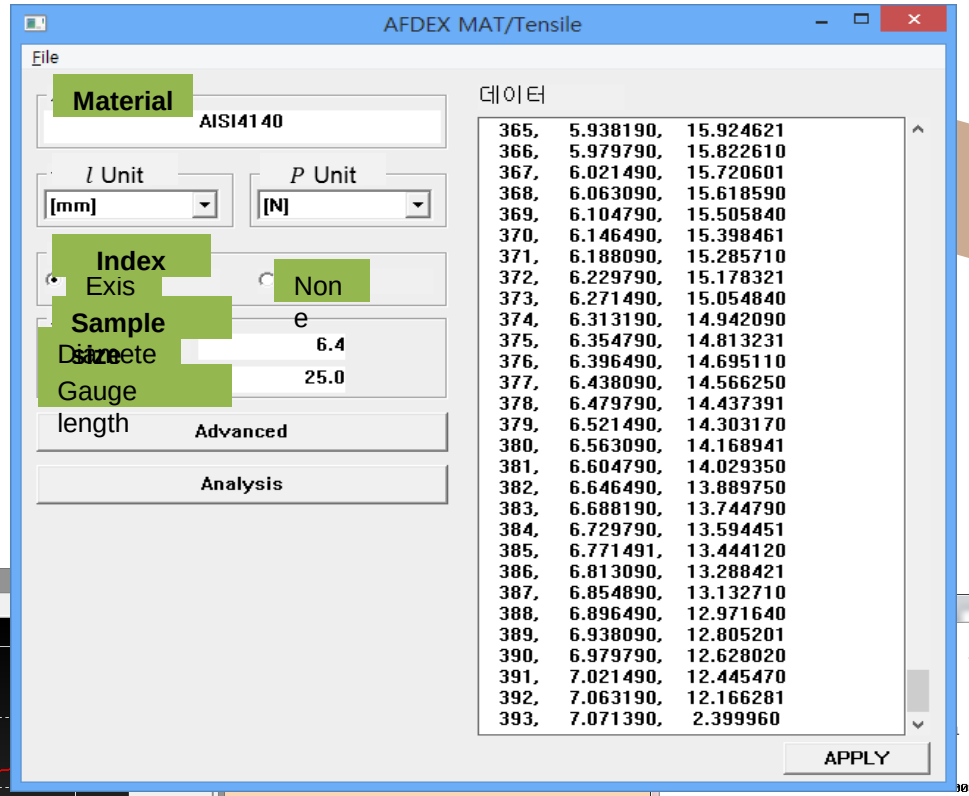
- ESW는 선조질강으로 기계적 성질이 우수하여 자동차부품 등으로 사용되고 있음. 이 교육 자료에서는 저변형경화 소재를 대표하여 사용되었음

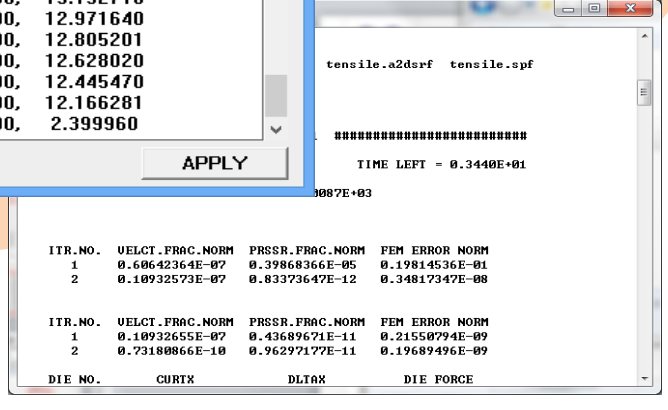
인장시험 정보를 이용한 상온 유동응력 획득

AFDEX/MAT 활용



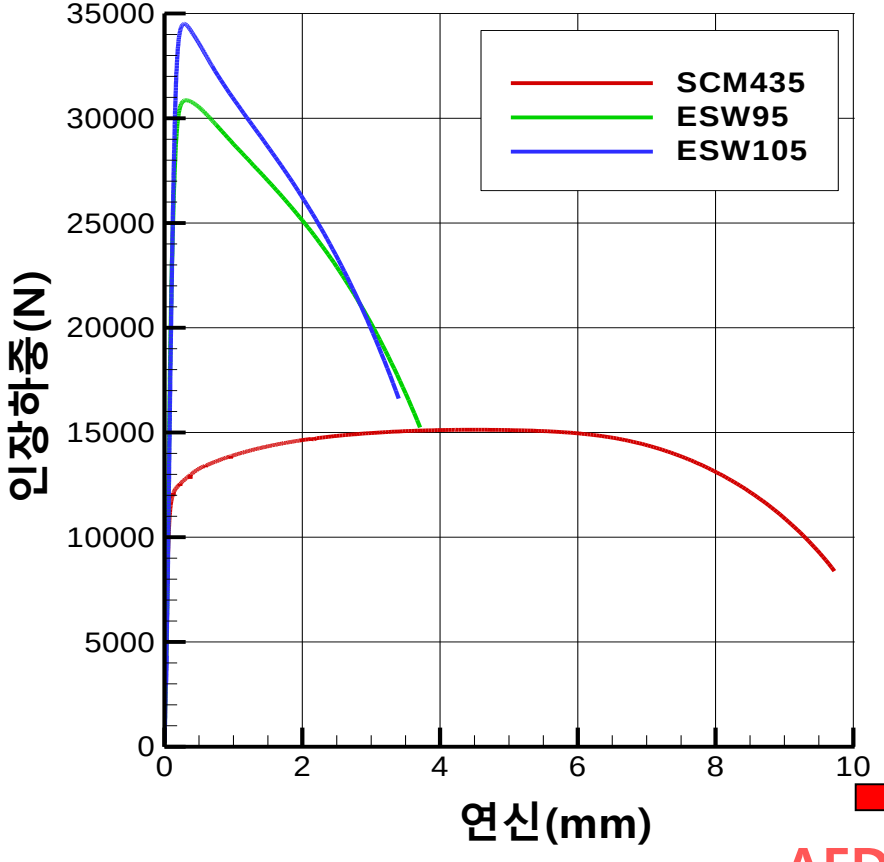




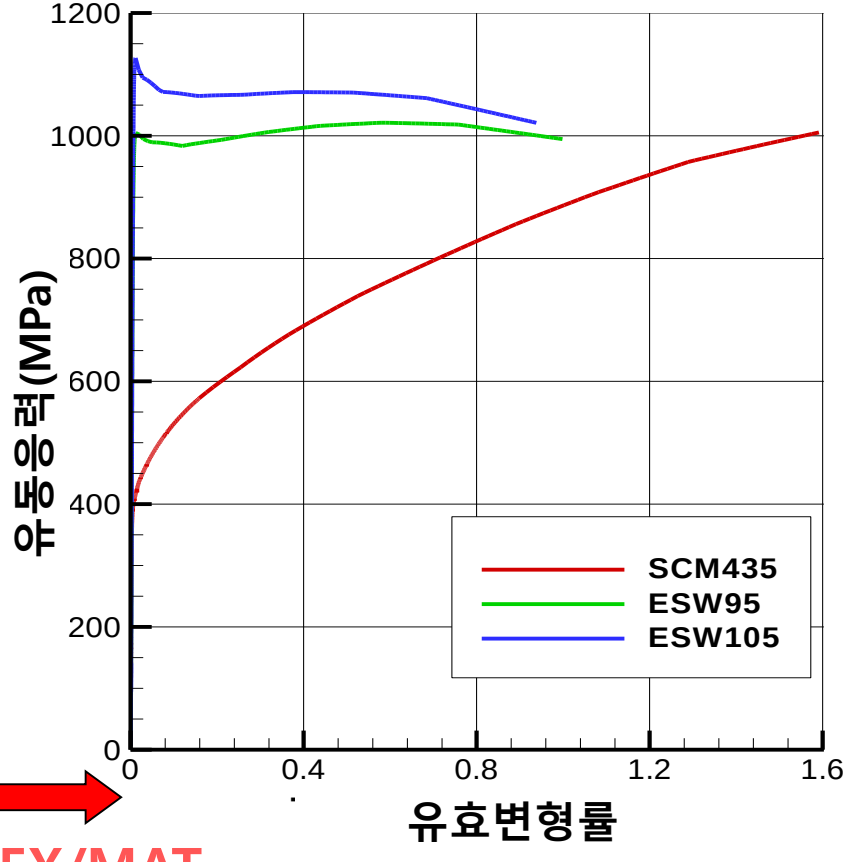


AFDEX/MAT의 적용 사례

인장하중과 변위 곡선

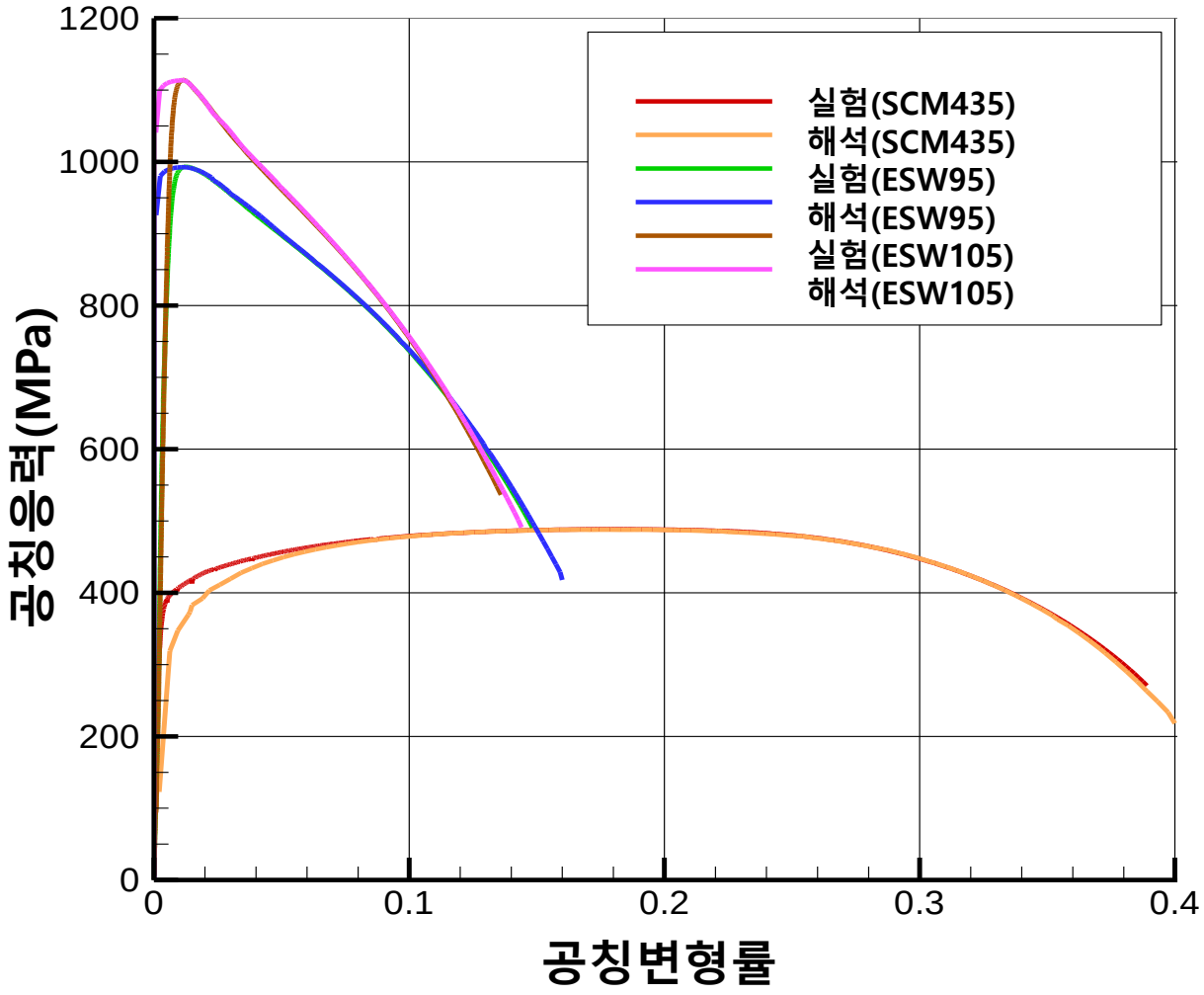


진응력-진변형률 곡선

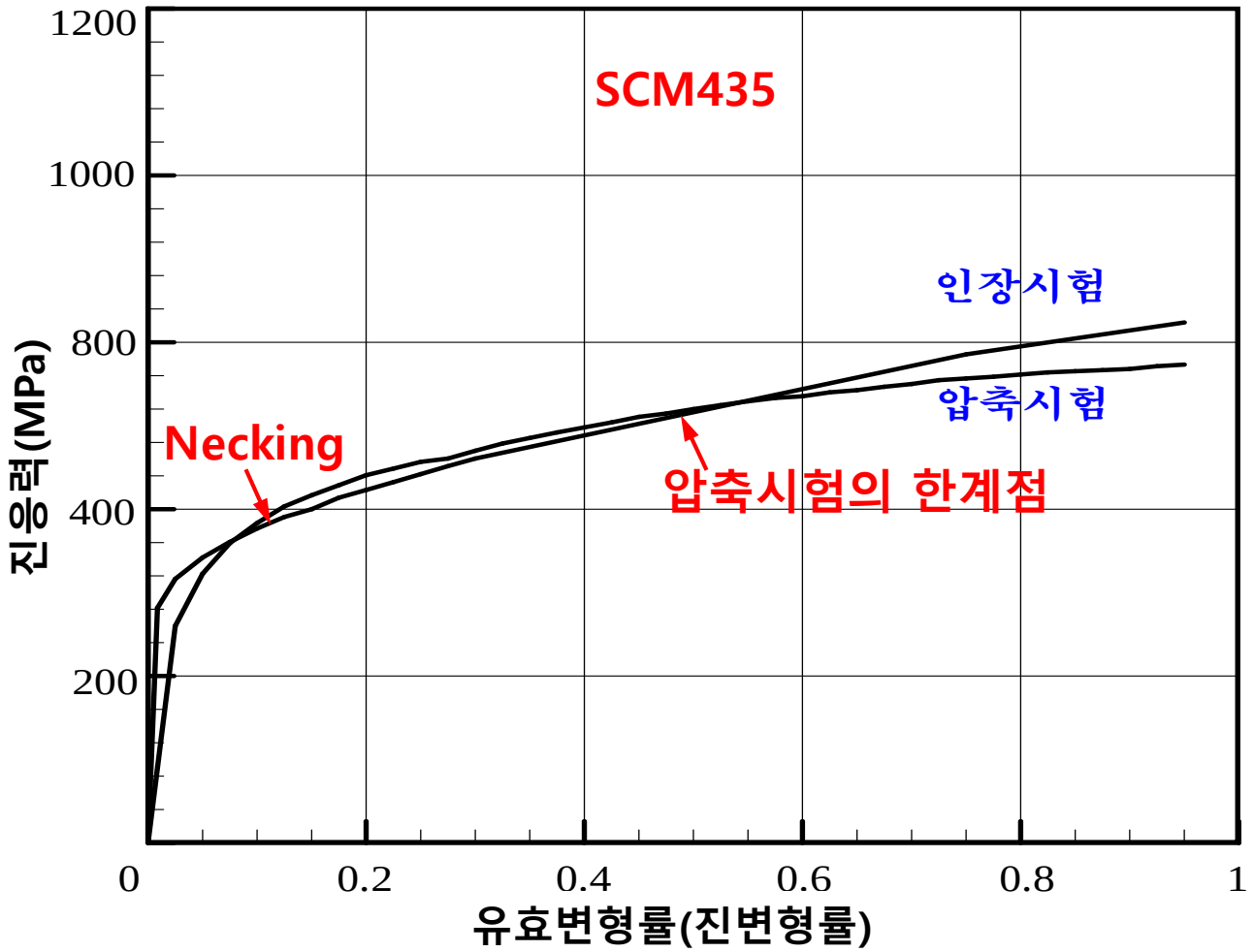


AFDEX/MAT

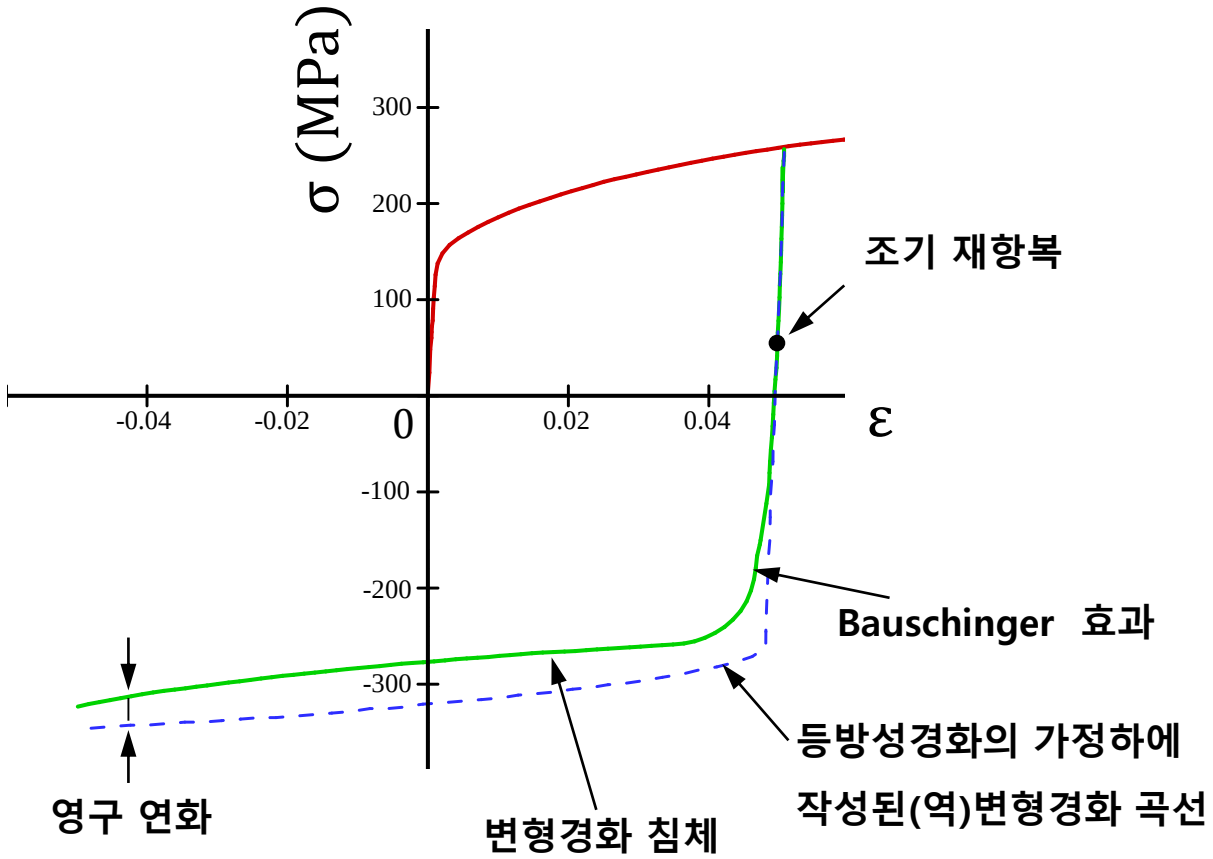
인장시험에 대한 예측결과 실험결과의 비교



압축시험과 인장시험으로 획득된 유동응력의 비교

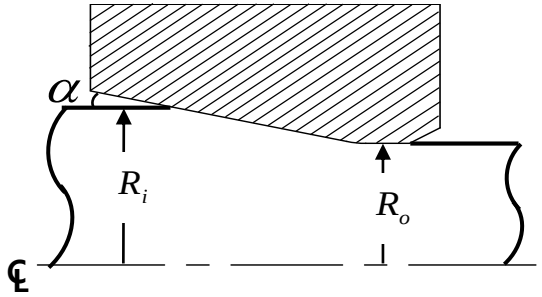


인장시험 후의 압축시험

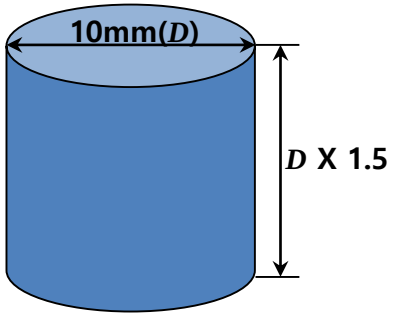

σ (MPa)
300
200
100
-100
-200
-300
-0.04
-0.02
0
0.02
0.04
ε
조기 재항복
Bauschinger 효과
등방성경화의 가정하에
작성된(역)변형경화 곡선
영구 연화
변형경화 침체

Bauschinger 효과 - 실험 방법/절차

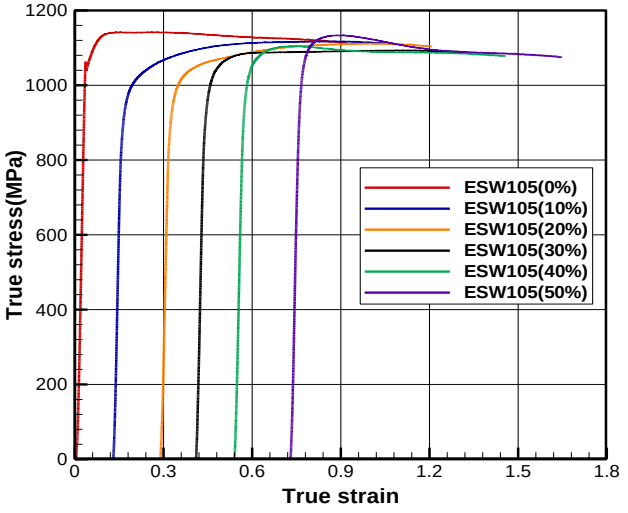
- 인발 단면감소율 = 10-50%
- 재료: SCM435, ESW105



인발



압축

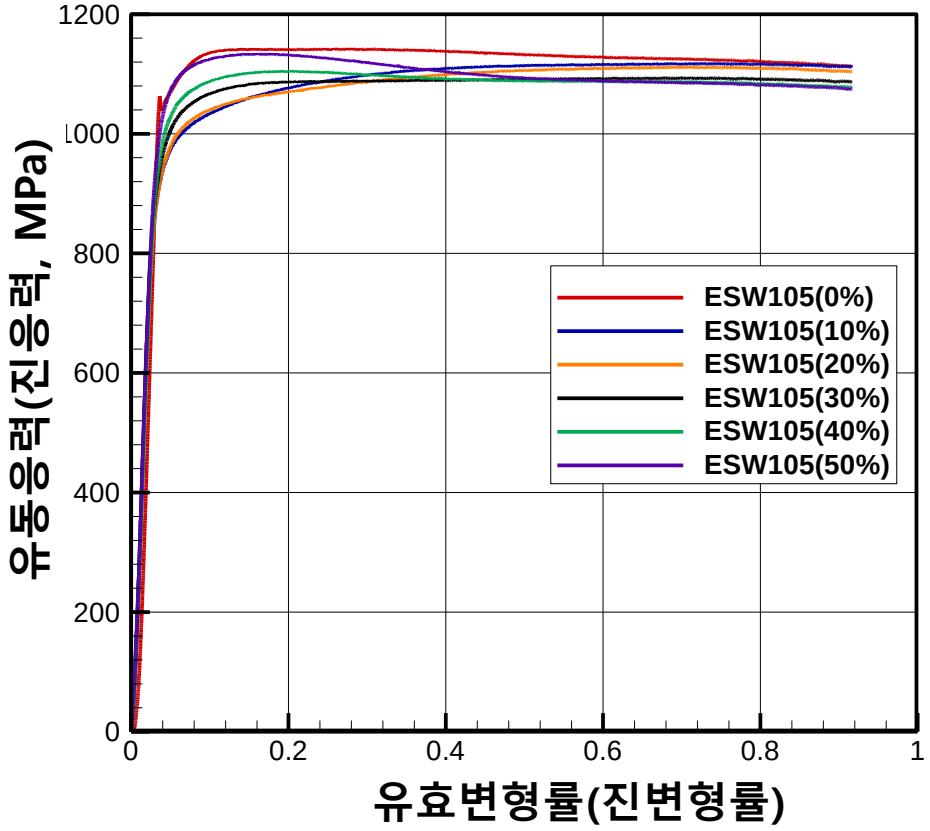


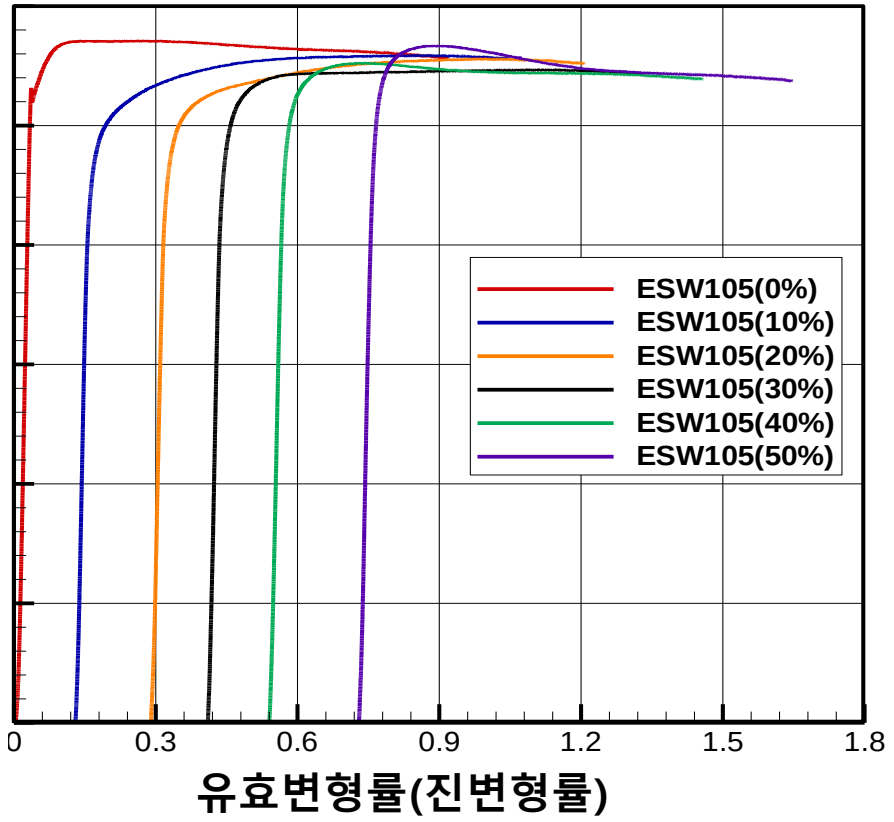
유동응력 획득

Bauschinger 효과 - 저변형경화 소재

ESW105

괄호 속은 신선율(단면감소율)

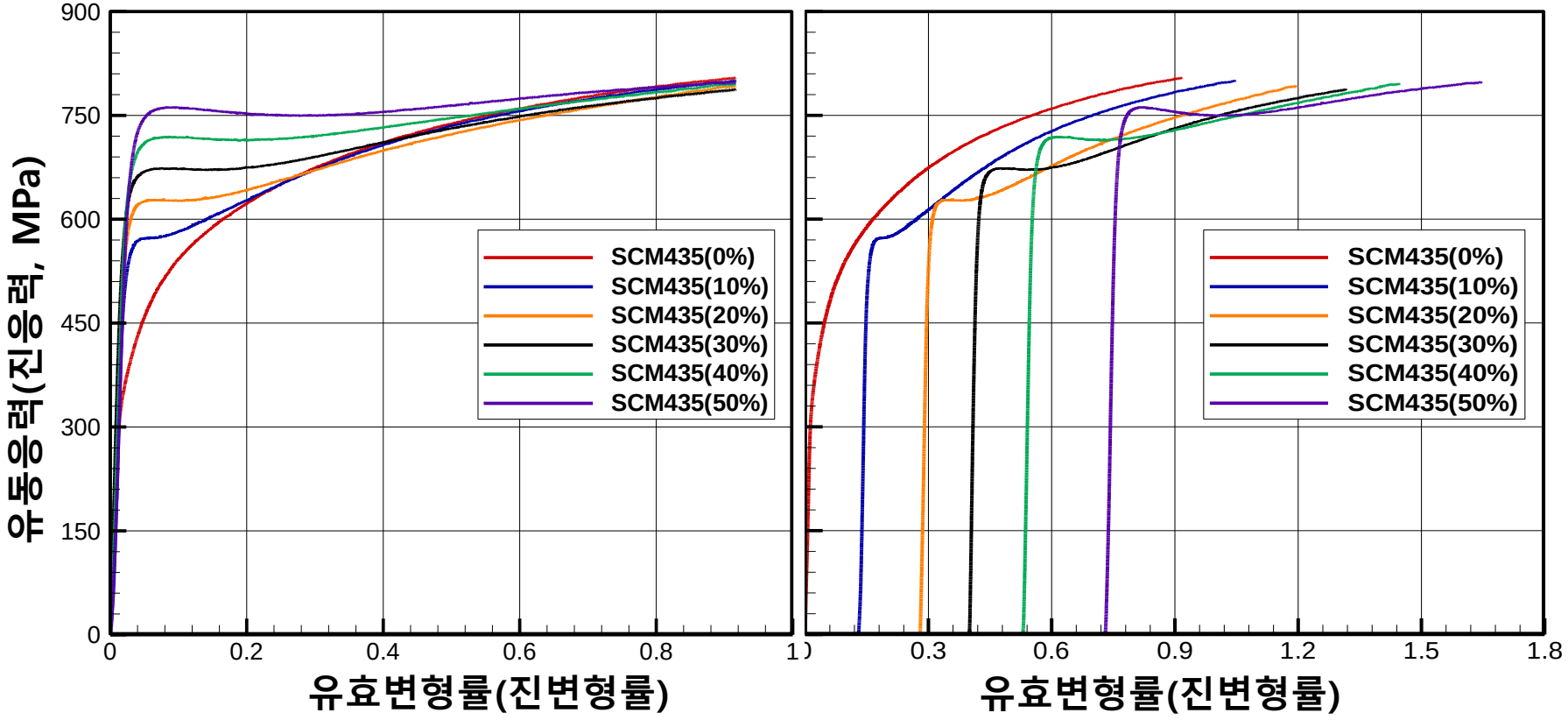




Bauschinger 효과 – 고변형경화 소재

SCM435

괄호 속은 신선율(단면감소율)



2.
고온 유동응력 획득

고온압축시험으로부터 열간유동응력 획득

고온압축시험 시,
속도별, 온도별로
생성되는 파일

No4447.CSV
No4448.CSV
No4449.CSV
No4450.CSV
No4451.CSV
No4452.CSV
No4453.CSV
No4454.CSV
No4455.CSV
No4456.CSV
No4457.CSV
No4458.CSV
No4459.CSV
No4460.CSV
No4461.CSV
No4462.CSV
No4463.CSV
No4464.CSV
No4465.CSV
No4466.CSV
No4467.CSV
No4468.CSV
No4469.CSV
No4470.CSV
No4471.CSV
No4472.CSV
No4473.CSV
No4474.CSV
No4475.CSV
No4476.CSV

어떻게 많은 데이터를
읽어서 한 번에 필요한
정보를 추출해 낼까?

$$\bar{\sigma} = C(\varepsilon, T)\dot{\bar{\varepsilon}}^{m(\varepsilon,T)}$$

최소자승법

사용자의 선택

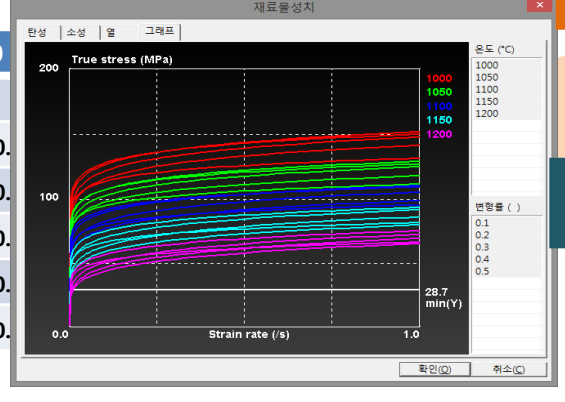
-일련번호 유/무 선택
-길이 단위 [mm, inch 등] 선택
-하중 단위 [kN, lb, kg 등] 선택
-시험 온도 및 속도 선택

사용자가 선택한 포맷의
압축시험 데이터 입력

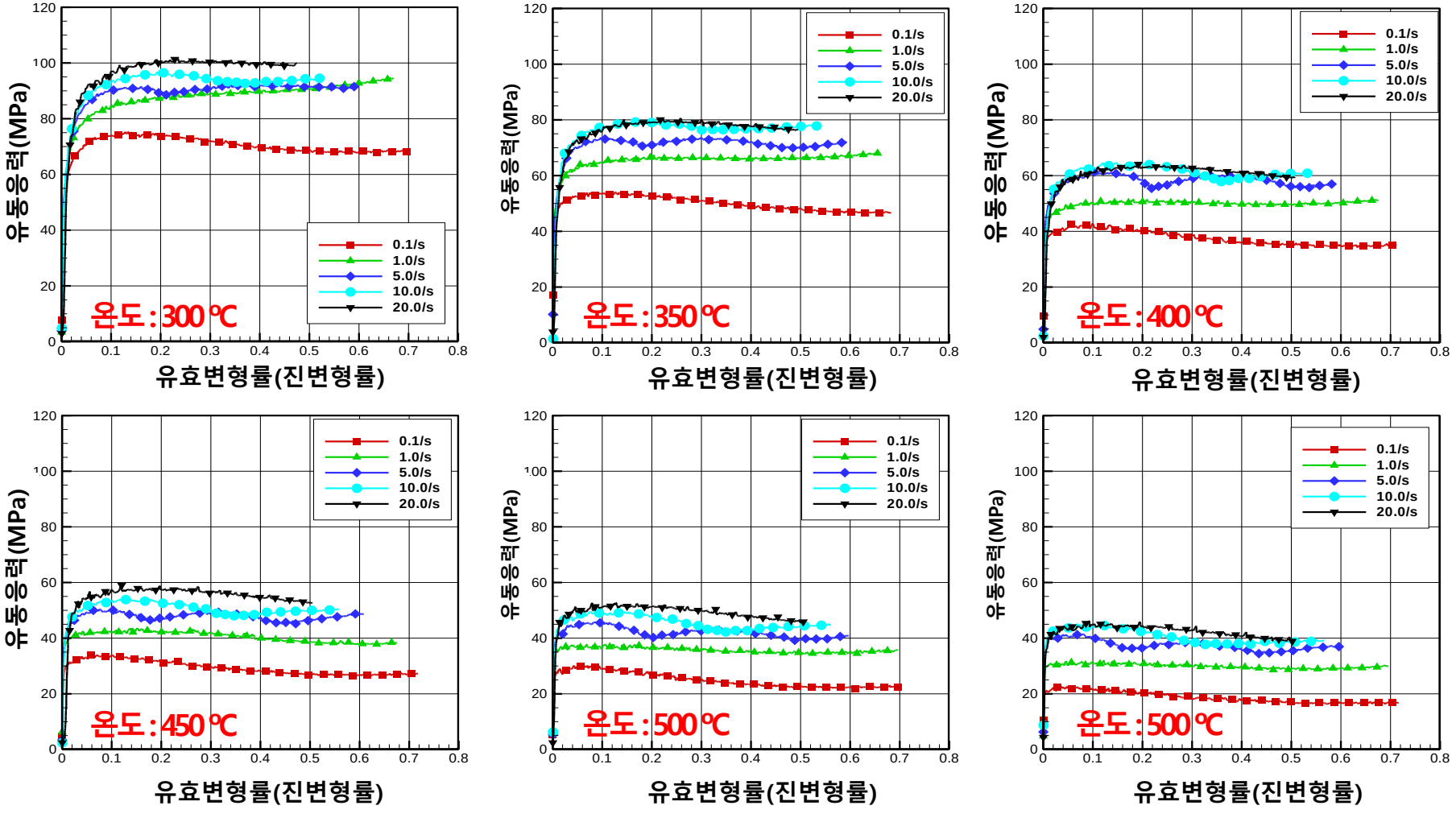
데이터 체크

AFDEX용 재료 물성
파일 추출

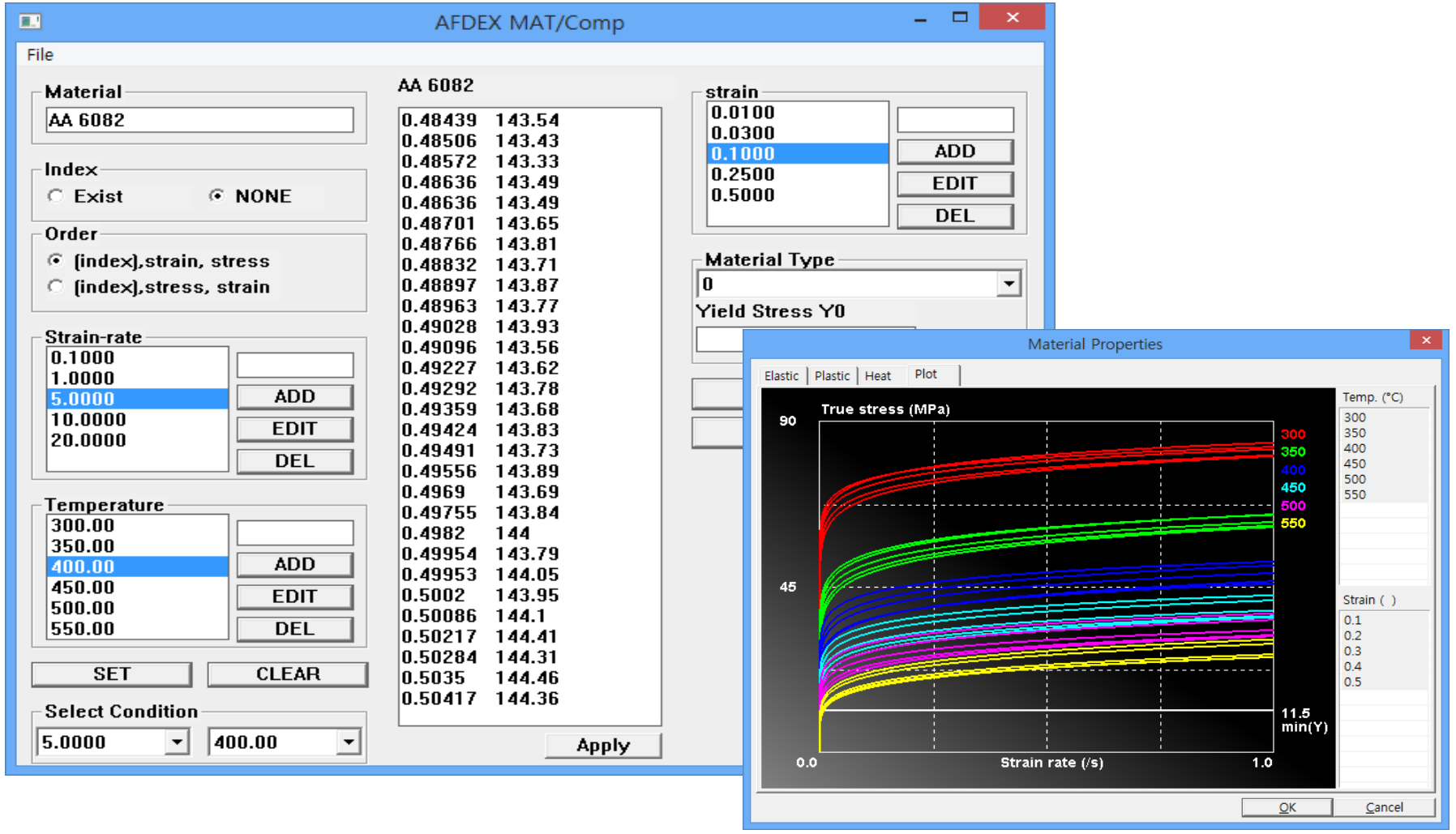
Temp.	1000		1050		1100	
Strain	C	m	C	m	C	
0.1	111.60	0.0640	94.099	0.0707	80.562	0.
0.2	124.50	0.0706	105.57	0.0743	90.973	0.
0.3	123.13	0.0796	105.65	0.0808	89.463	0.
0.4	118.48	0.0855	101.16	0.0869	83.243	0.
0.5	112.97	0.0894	96.604	0.0833	78.159	0.



Al6082의 고온유동응력 획득 - 압축시험



Al6082의 고온유동응력 획득 - AFDEX/MAT 활용



Al6082의 고온유동응력 획득 - 유동응력 DB 구축

$$\bar{\sigma} = C(\varepsilon, T)\dot{\bar{\varepsilon}}^{m(\varepsilon,T)}$$

최소자승법

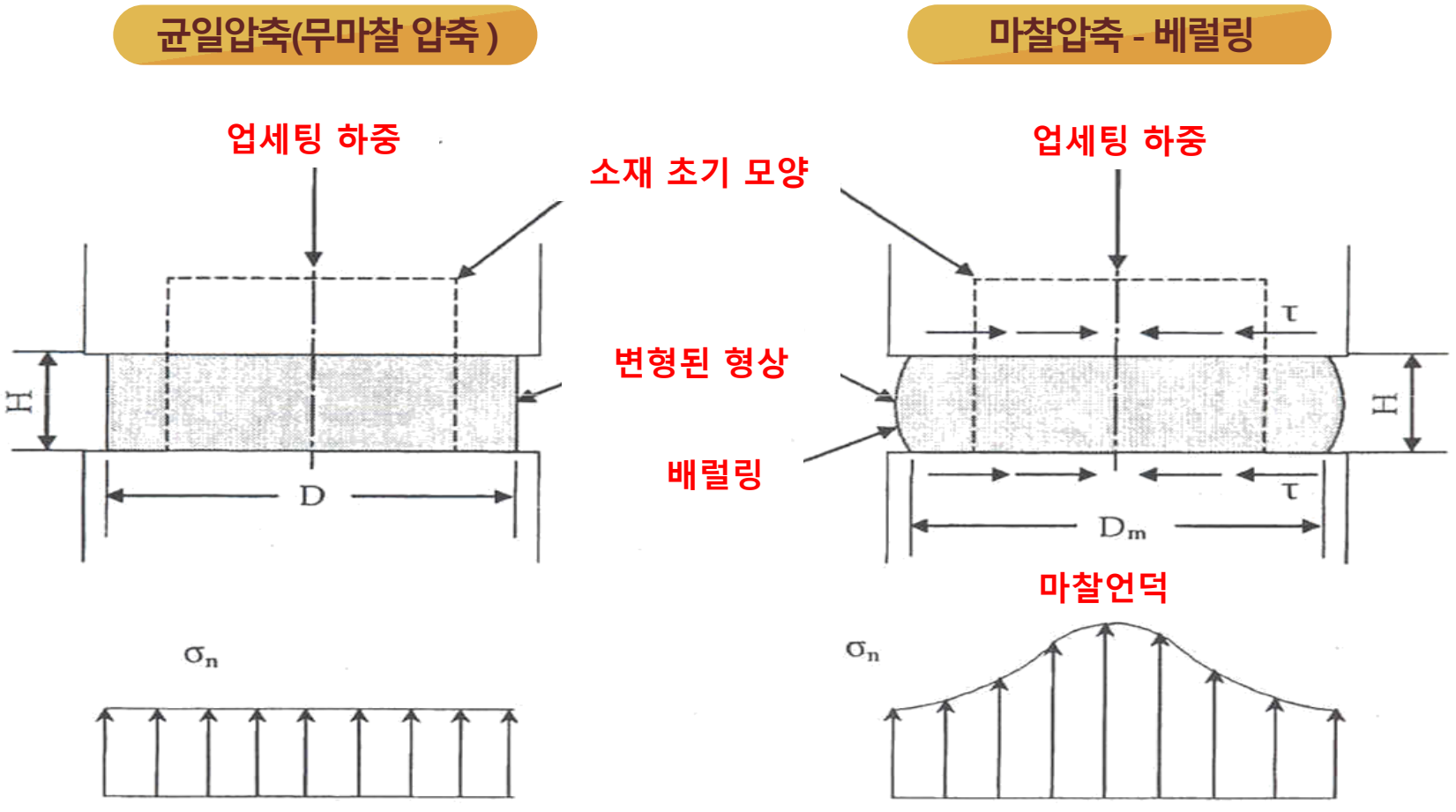
온도 [°C]	변형률 [mm/mm]	고온 강도계수, C [MPa]	변형률속도 의존지수, m
300	0.01	59.947877	0.013891
	0.03	74.511327	0.038682
	0.10	83.491843	0.049373
	0.25	84.639311	0.055143
	0.50	83.612423	0.060983
350	0.01	51.981840	0.027419
	0.03	60.007117	0.050479
	0.10	64.263350	0.069293
	0.25	64.075202	0.078071
	0.50	61.962331	0.083067
400	0.01	42.868227	0.022956
	0.03	47.728667	0.063042
	0.10	51.267648	0.074938
	0.25	49.476272	0.090539
	0.50	47.302731	0.093467

온도 [°C]	변형률 [mm/mm]	고온 강도계수, C [MPa]	변형률속도 의존지수, m
450	0.01	37.276146	0.076303
	0.03	40.639365	0.089144
	0.10	42.489470	0.100116
	0.25	40.592783	0.111849
	0.50	37.370445	0.121652
500	0.01	34.534427	0.076508
	0.03	36.455361	0.101598
	0.10	37.456420	0.108473
	0.25	34.726328	0.125264
	0.50	32.353452	0.125031
550	0.01	29.694233	0.119925
	0.03	31.024802	0.124556
	0.10	31.136650	0.137385
	0.25	29.401557	0.142721
	0.50	27.153190	0.141299

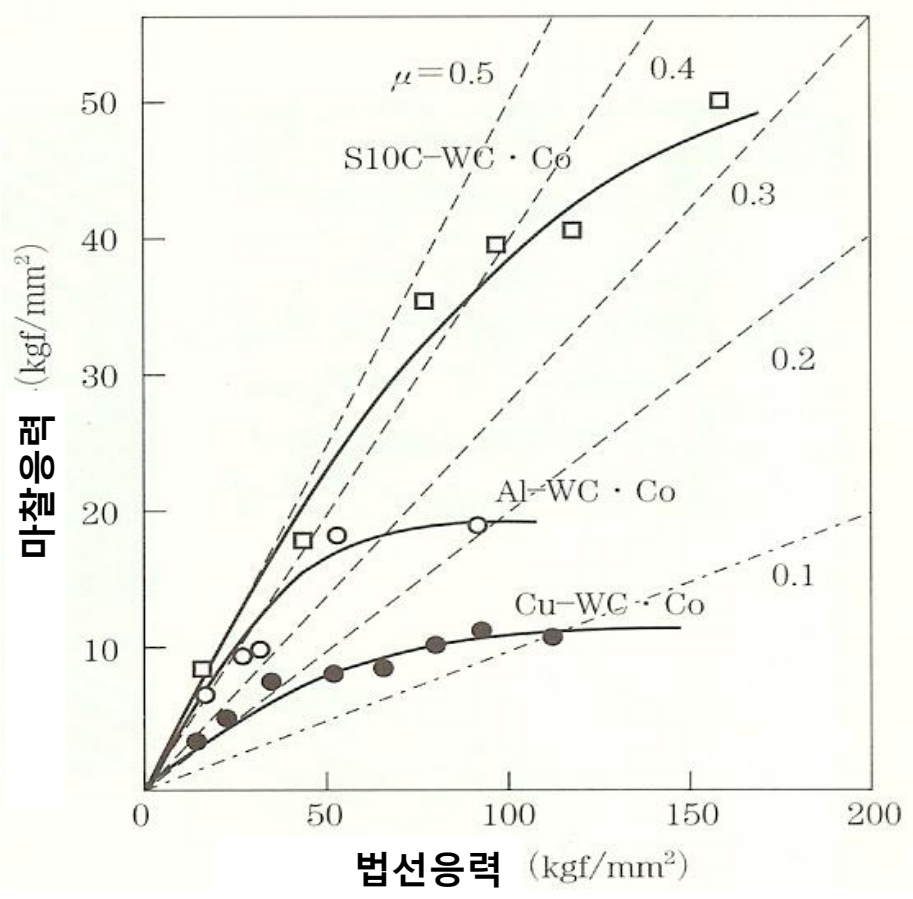
3.

마찰, 윤활, 마모

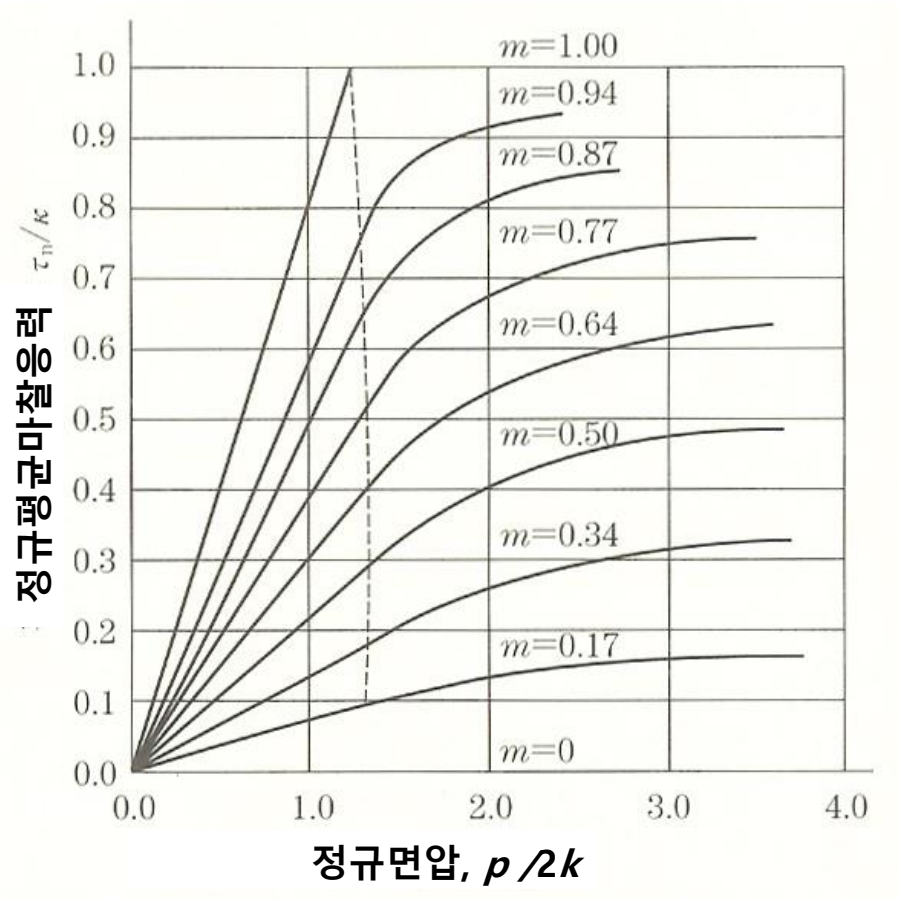
중실실린더 압축 - 업세팅, 마찰언덕, 베럴링



접촉압력과 마찰응력

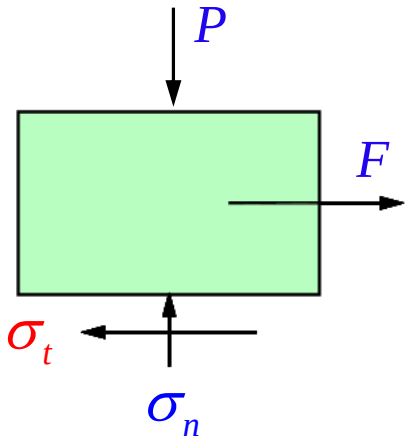


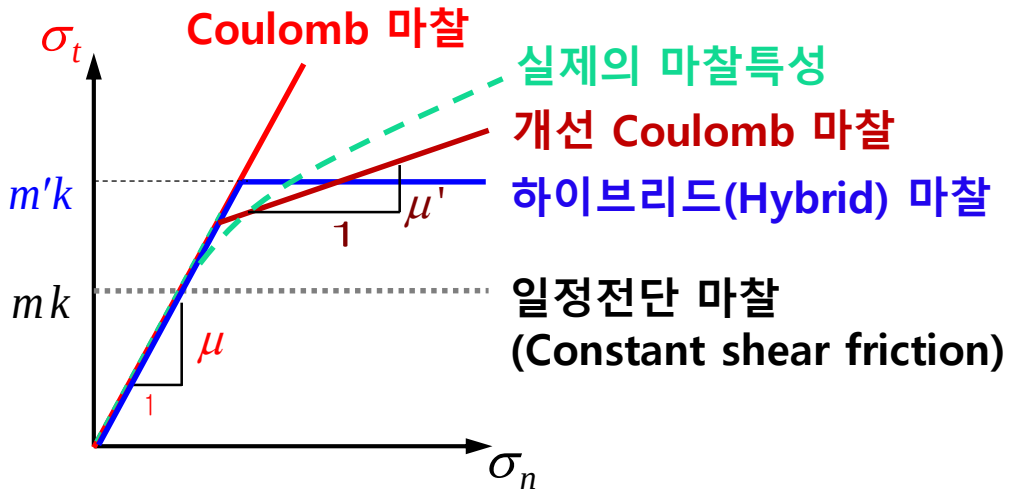
무윤활에 있어서의 각종 금속과 초경 합금과의 마찰응력의 법선응력 의존성



정규면압과 평균마찰전단응력의 관계

마찰법칙





Coulomb 마찰법칙

$$\sigma_t = -\mu\ \sigma_n\ sign(v_t)$$

마찰계수 법선응력

일정전단 마찰법칙

$$\sigma_t = m\ k\ sign(v_t)$$

마찰상수 순수전단항복응력

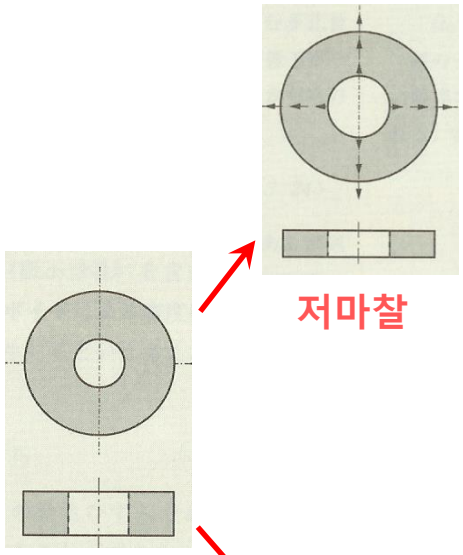
하이브리드(Hybrid) 마찰법칙

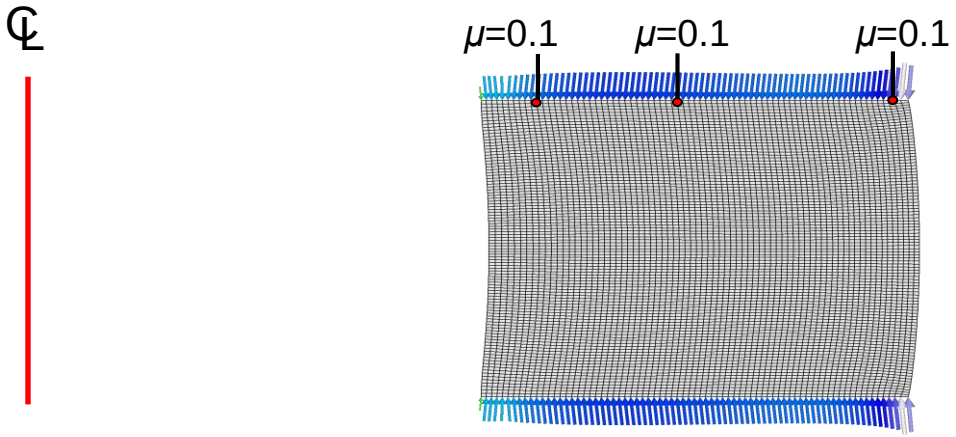
$$\sigma_t = -\mu\sigma_n g(v_t - \bar{v}_t)$$

$$\sigma_t = m'k\ g(v_t - \bar{v}_t)$$

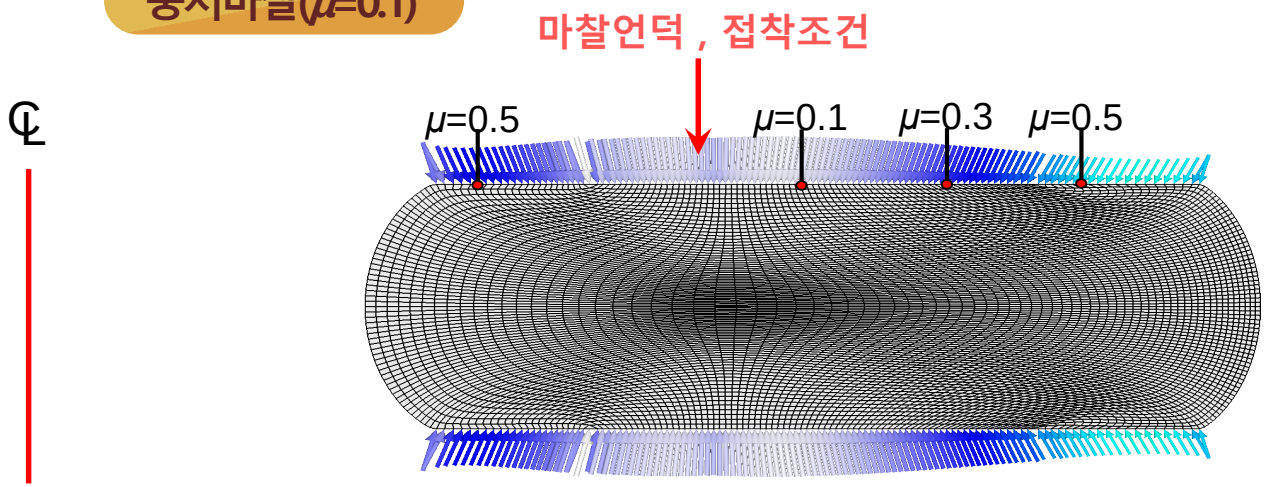
$$g = \left(-\frac{2}{\pi}\tan^{-1}\frac{(v_t - \bar{v}_t)}{a}\right)$$

링압축과 마찰응력



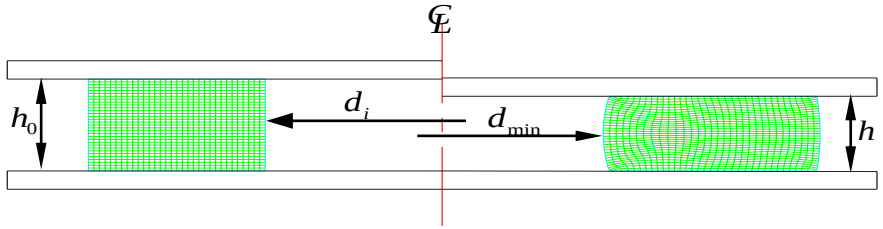


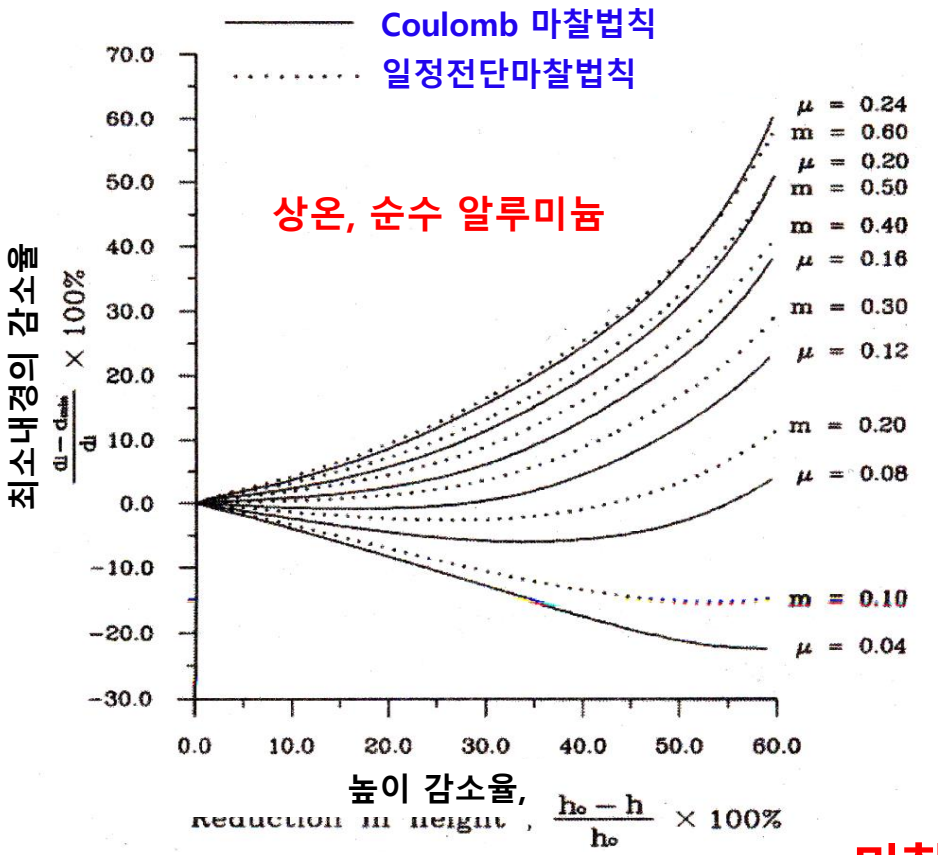
중저마찰(μ=0.1)

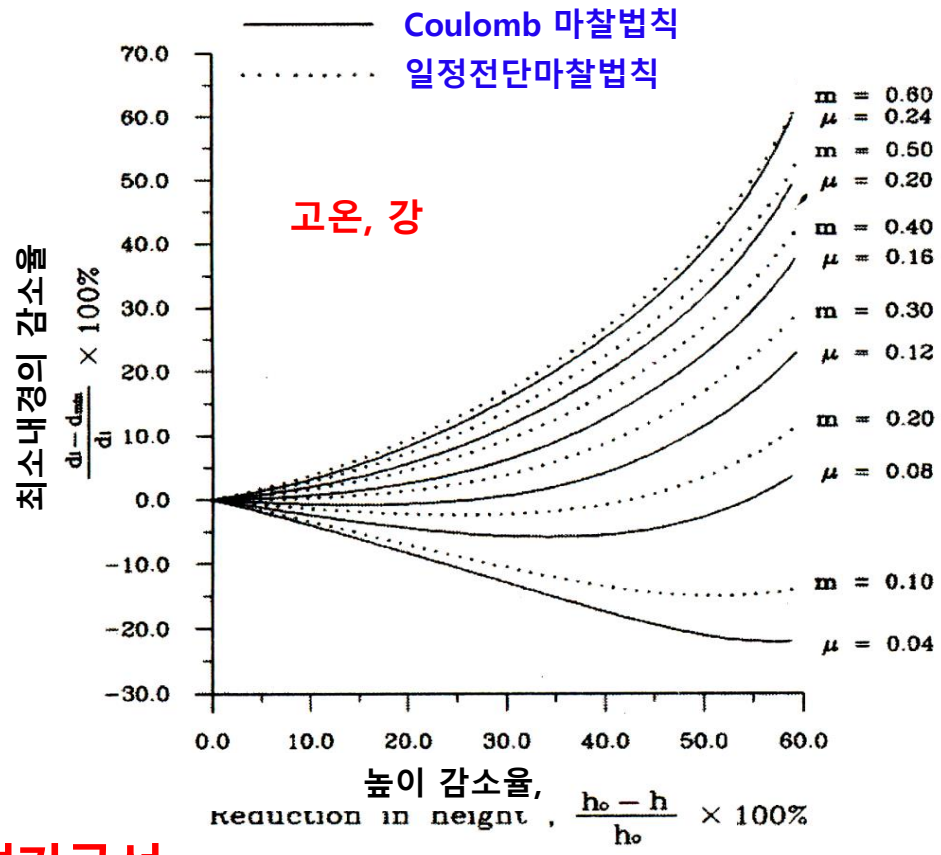


고마찰(μ=0.5)

마찰의 평가 - 링압축시험과 마찰평가곡선

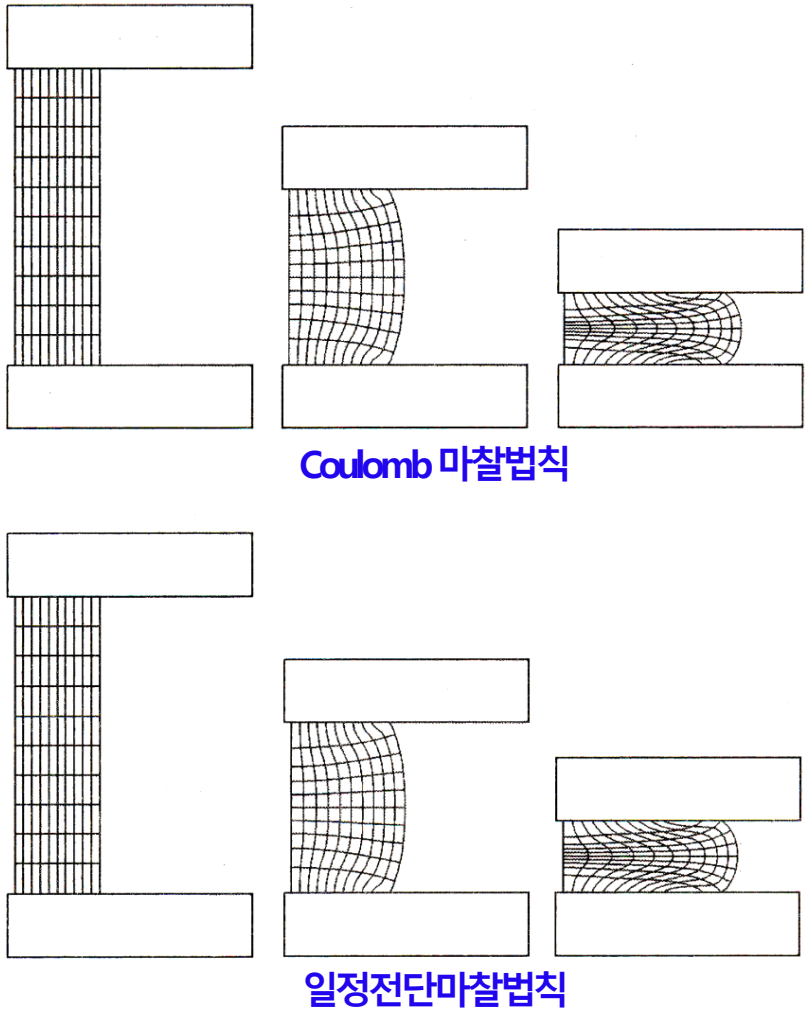




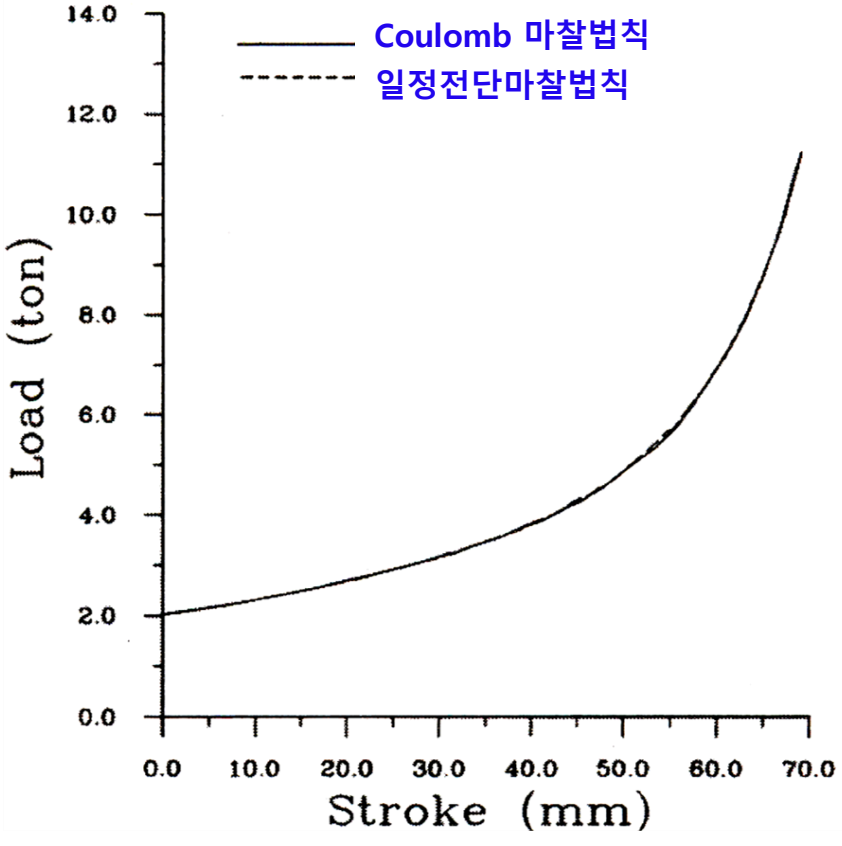


마찰평가곡선

저형상비 중실실린더 압축 시 마찰법칙의 비교

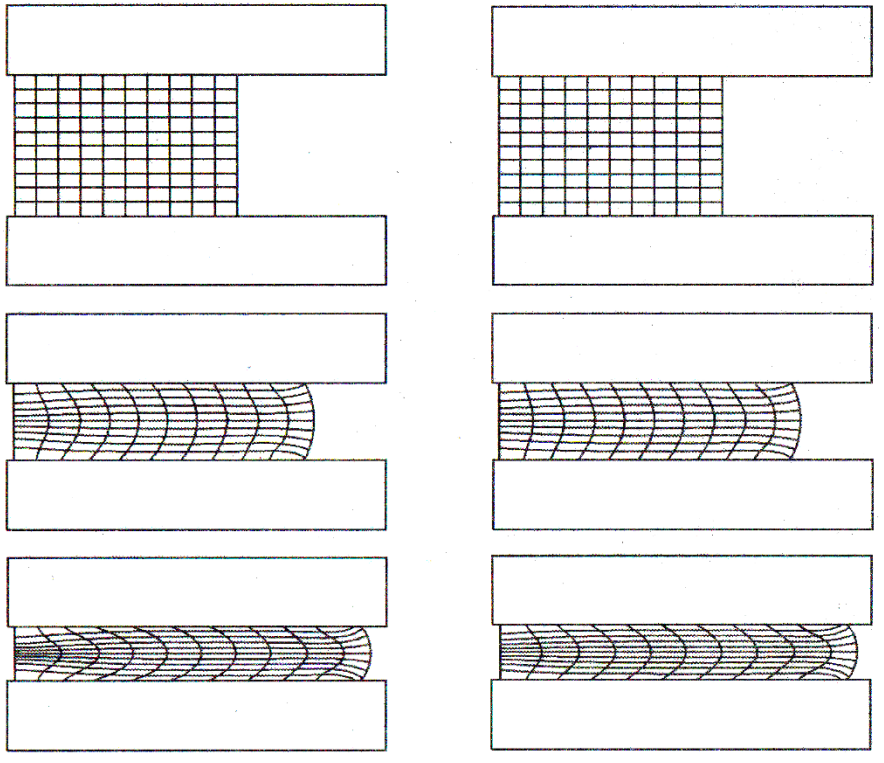


소성유동선도의 비교



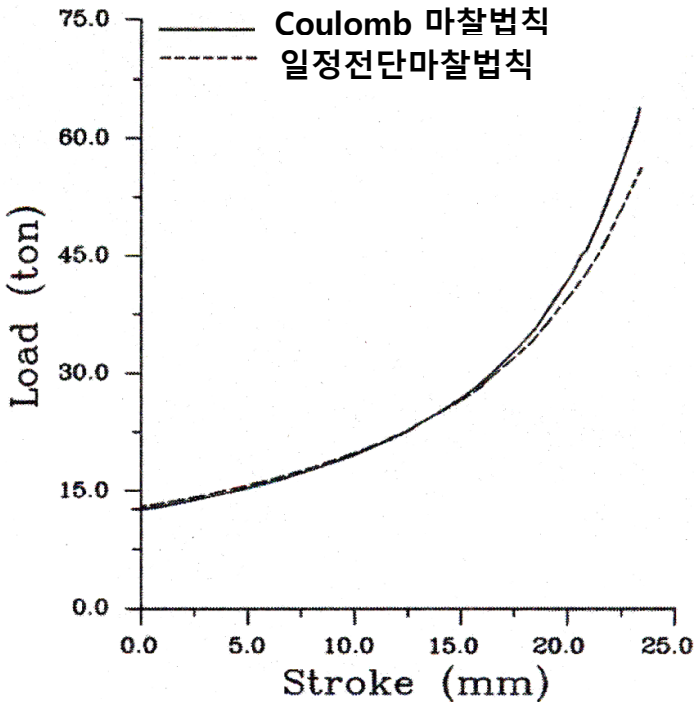
성형하중의 비교

고형상비 중실실린더 압축 시 마찰법칙의 비교



Coulomb 마찰법칙　　일정전단 마찰법칙

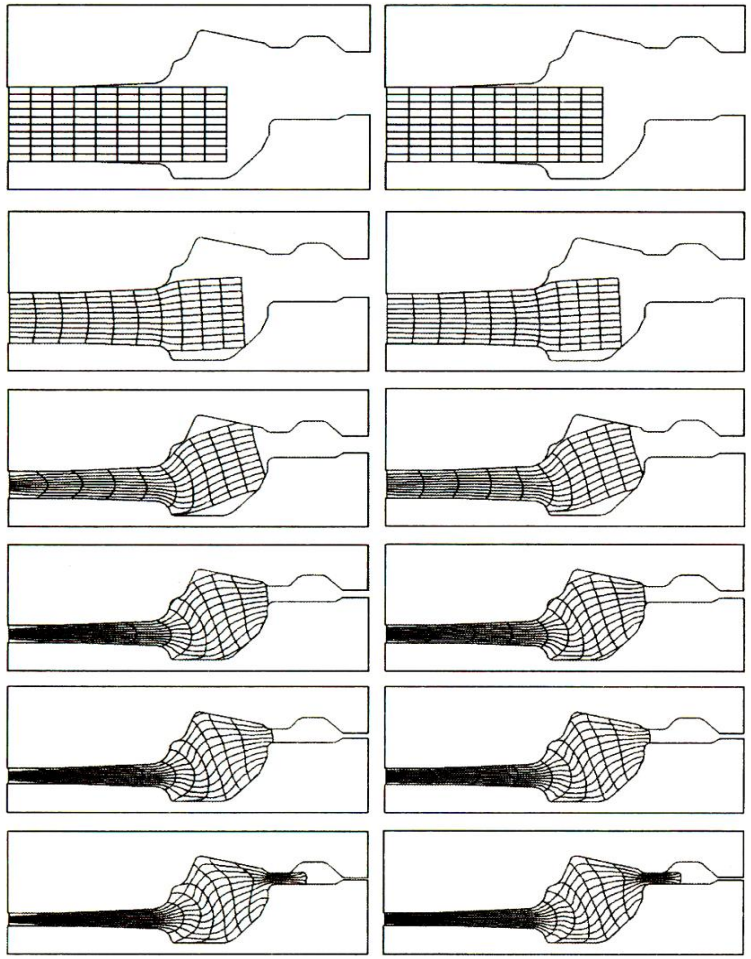
소성유동선도의 비교



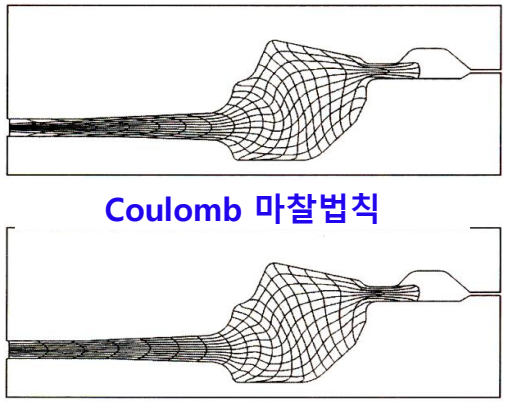
성형하중의 비교

마찰법칙에 따른 단조시뮬레이션 결과의 비교

링단조 시뮬레이션



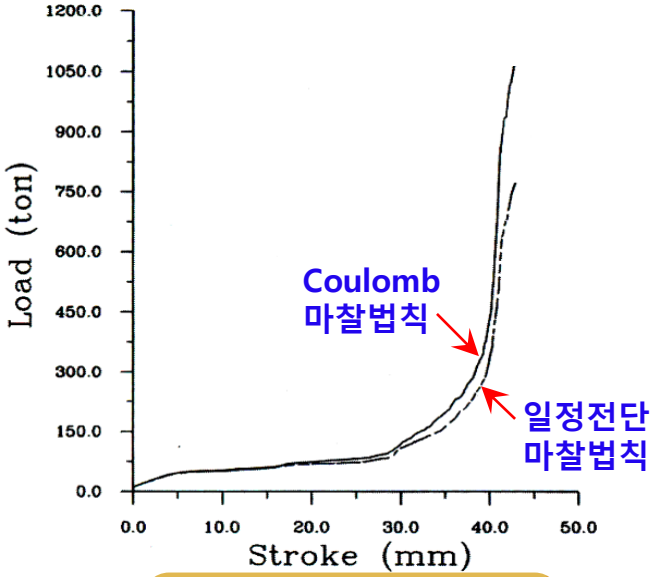
Coulomb 마찰법칙　　일정전단 마찰법칙



Coulomb 마찰법칙

일정전단마찰법칙

소성유동선도의 상세 비교



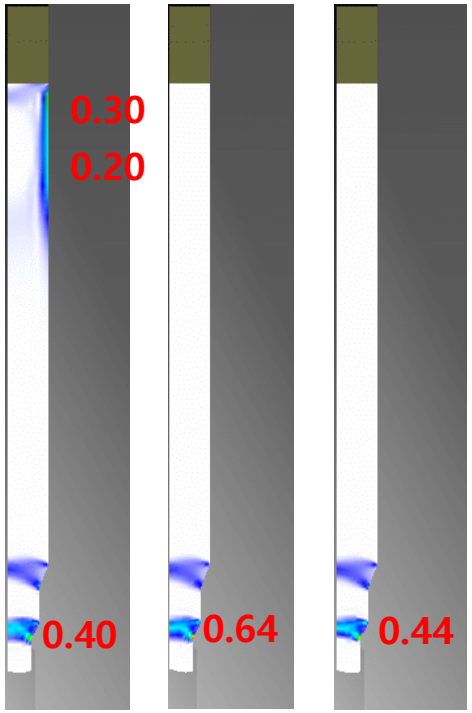
성형하중의 비교

극단적인 경우와 마찰법칙

전방압출

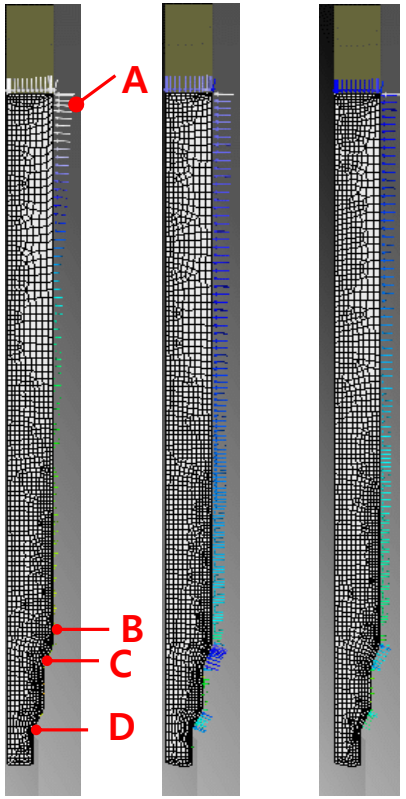
- 장 컨테이너
- 대 단면감소율

유효변형률속도



Coulomb 일정전단 하이브리드

법선응력

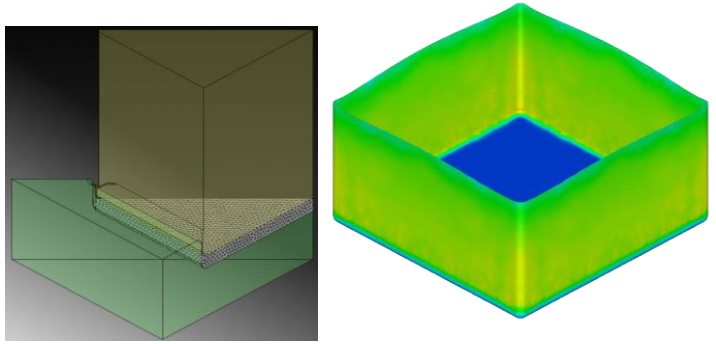


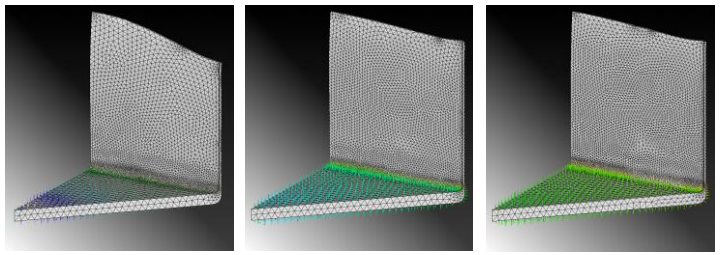
Coulomb 일정전단 하이브리드

	Coulomb	일정전단	하이브리드
A	-12551.1	-2945.3	-4109.3
B	-2095.4	-2513.3	-2585.1
C	-2195.9	-1770.0	-2129.0
D	-1716.4	-1798.5	-1700.0

3D – 후방압출

- 대 단면감소율

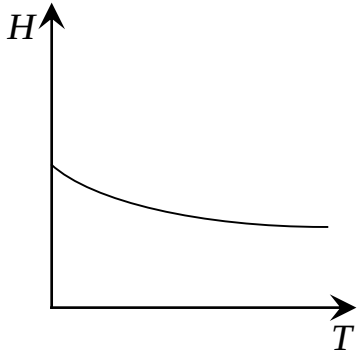
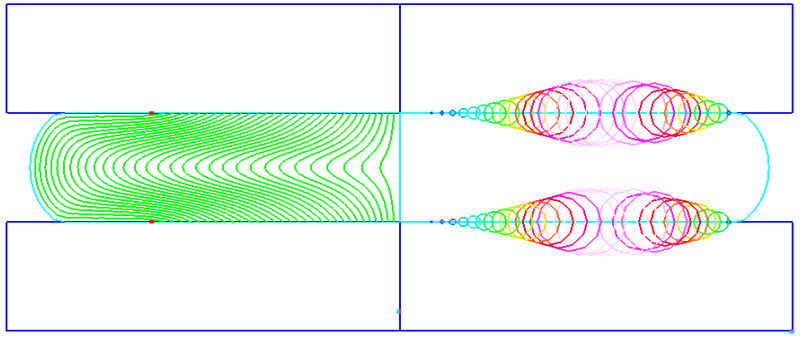
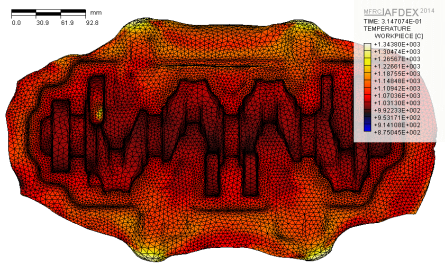
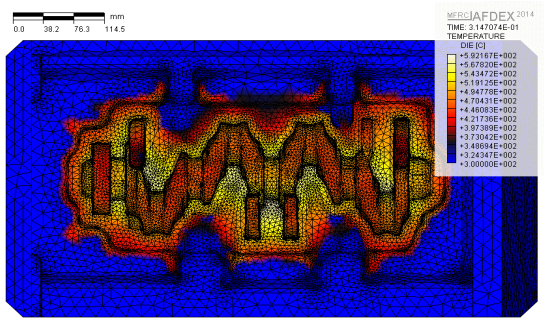
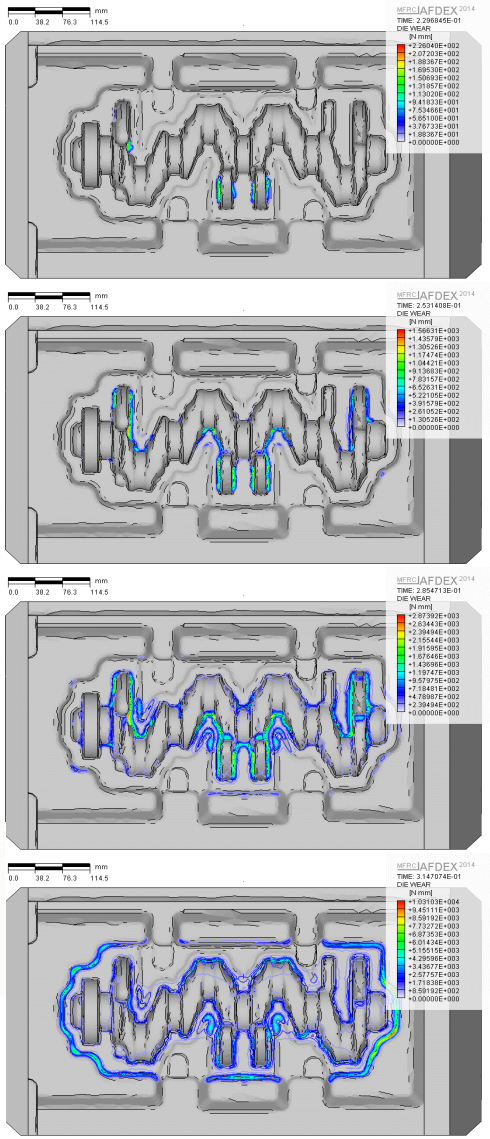




Coulomb 마찰 일정전단마찰 하이브리드마찰

마모 - 연삭마모

$$w = \int_0^t \sigma_t \left| u_t - \sigma_t^D \right| dt$$ ← 연삭마모(Abrasive attrition) 모델

$$w = k \int_0^t \frac{\sigma_n \left| u_t - u_t^D \right|}{3H} dt$$

$$H = H_0 + H_1 e^{-H_2 T}$$