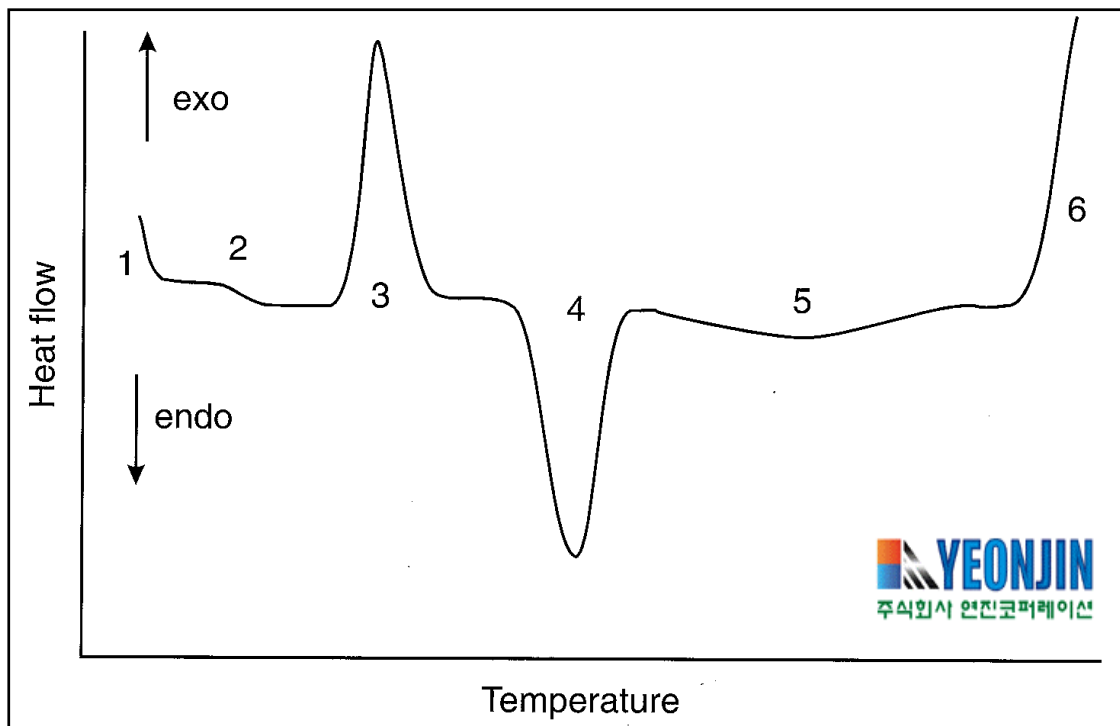


열분석기 응용사례 (Thermal Analyzer Application)

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1. DSC (Differential Scanning Calorimeter; 시차주사열량계)

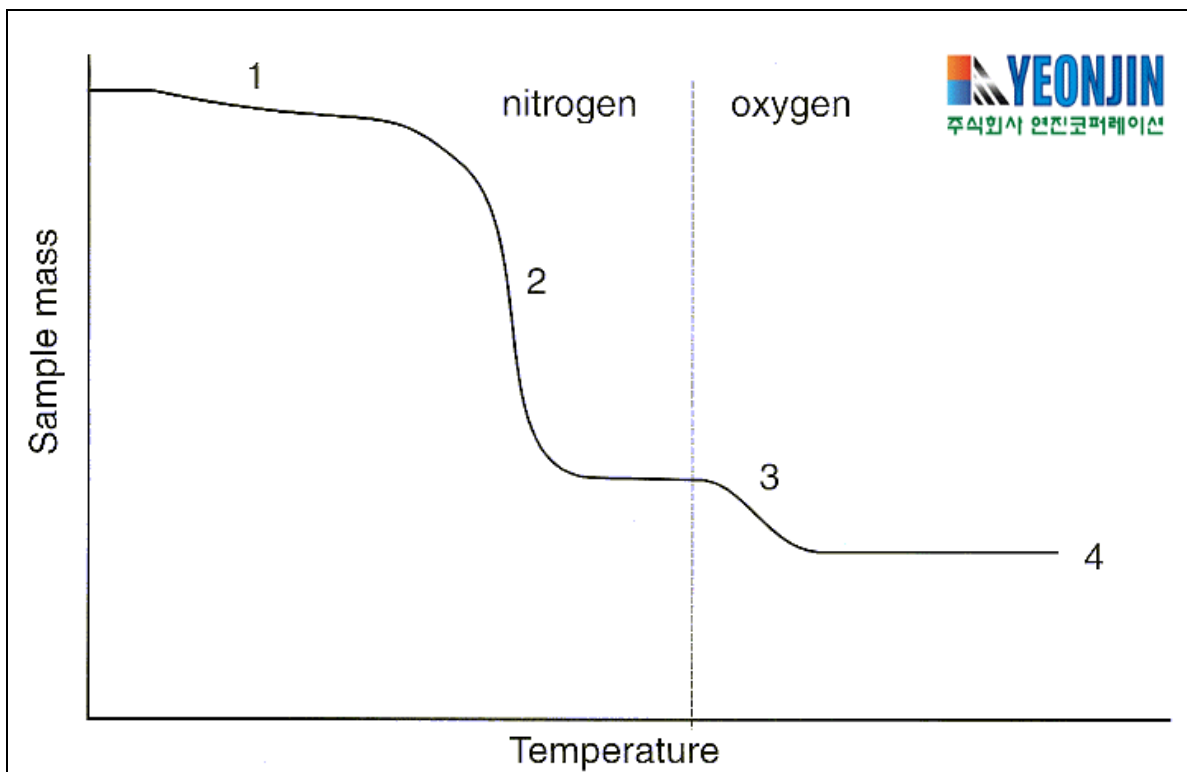


- 엔탈피 변화 (Enthalpy change) 측정
- Glass transition temperature (유리전이온도)
- Temperature of fusion (용융점, T_m)
- Heat of fusion (용융열, ΔH)
- Crystallinity (결정화도)
- Melting behavior, fraction melted (용융거동)

- Temperature of crystallization (결정화 온도)
- Heat of crystallization (결정화열, ΔH)
- Cold crystallization (재결정화)
- Polymorphism (change of crystal modification)
- Evaporation, desorption (moisture), vaporization
- Thermal decomposition (pyrolysis, depolymerization)
- Thermal stability (열안정성)
- Oxidative degradation, oxidation stability (산화안정성)
- Specific heat capacity (비열)

그림 설명. 고분자의 **DSC curve** : 1. initial startup deflection 2. glass transition 3. crystallization 4. melting 5. vaporization decomposition

2. TGA (Thermogravimetric Analyzer; 열중량측정기)

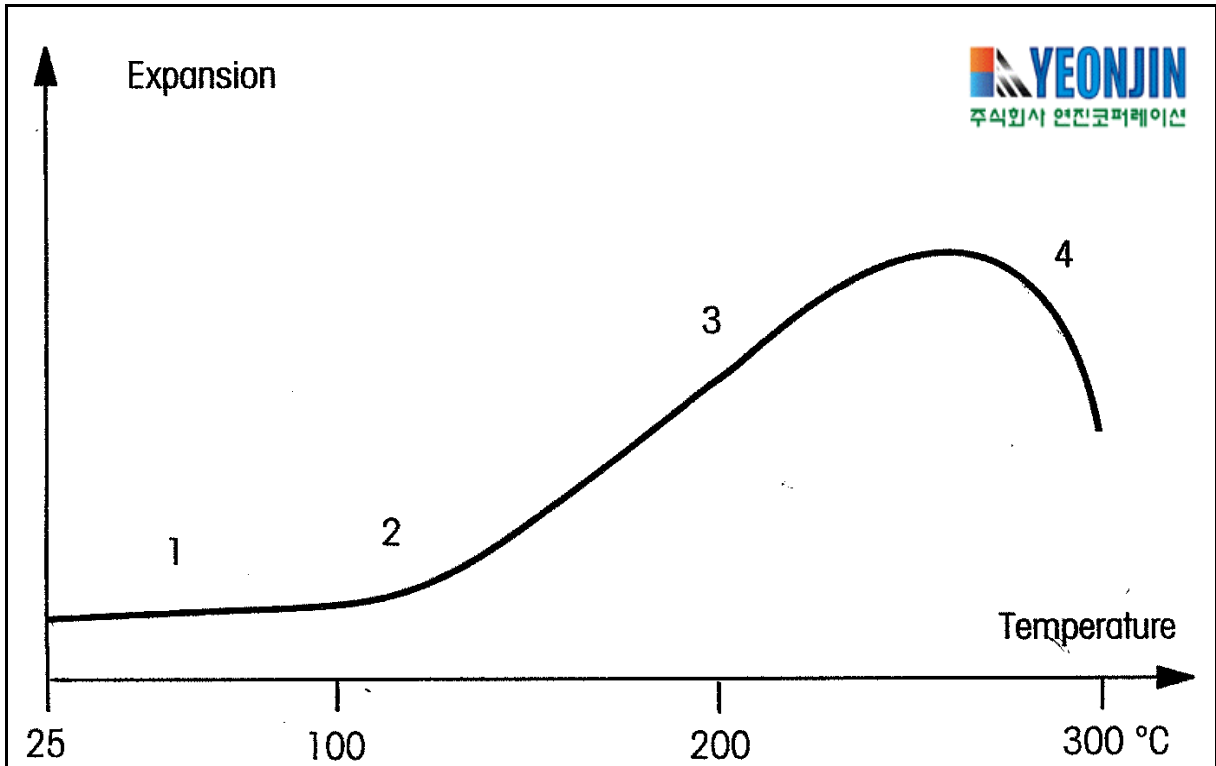


조성에 따른 질량의 증감 측정

- Evaporation, desorption (moisture), vaporization
- Thermal decomposition (pyrolysis, depolymerization)
- Thermal stability (열안정성)
- Oxidative degradation, oxidation stability (산화안정성)
- Compositional analysis (volatiles, polymer, carbon black, ash, filler, glass fibers)

그림 설명. 고분자의 TGA curve :1. 휘발성분의 증발에 의한 질량손실 2. pyrolysis 3. 탄소의 연소(불활성 조건에서 산화조건으로 전환 후) 4. 잔류물(residue)

3. TMA (Thermomechanical Analyzer; 열기계분석기)

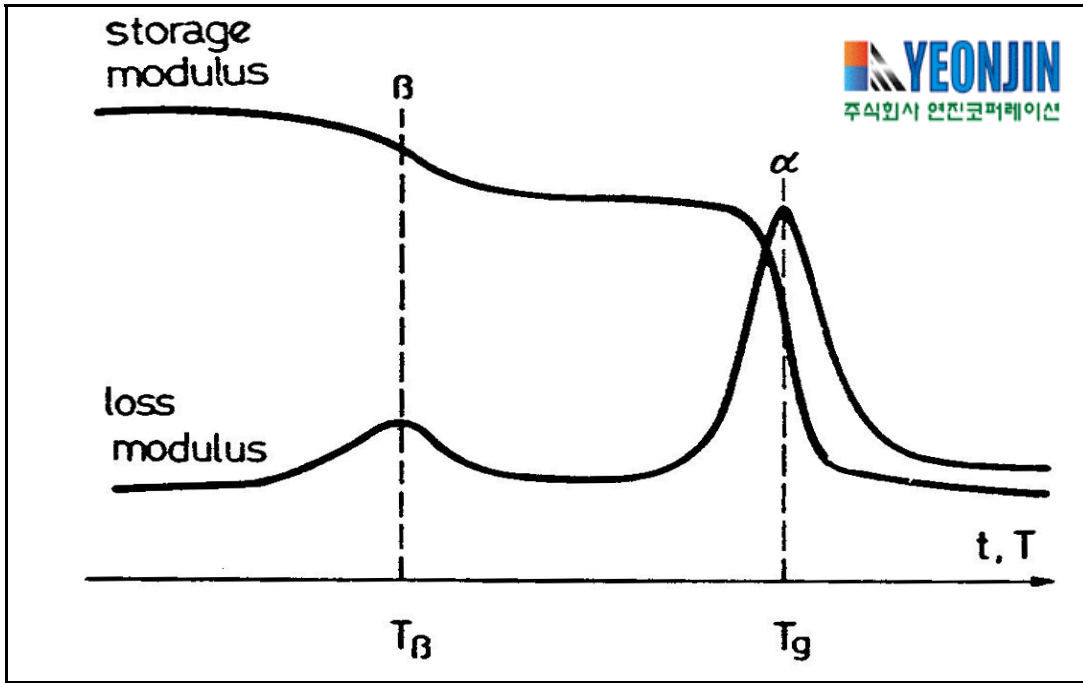


- 크기(치수) 변화 (dimensional change) 측정
- Expansion and shrinkage behavior (팽창 및 수축 거동)
- Expansivity (Coefficient of linear expansion)
- Coefficient of Thermal Expansion (열팽창 계수, CTE)
- Young's shear modulus, stiffness
- Polymorphism (change of crystal modification)
- Glass transition (유리전이, Tg)
- Softening (연화점)
- Thermal decomposition (pyrolysis, depolymerization)
- Thermal stability (열안정성)
- Oxidative degradation, oxidation stability (산화안정성)
- Temperature of fusion (용융점, Tm)
- Melting behavior, fraction melted (용융거동)
- Cold crystallization (재결정화)

그림 설명. 고분자의 TMA curve(under low comprehensive stress) : 1. 유리전이 이전의 팽창 2 유리

전이(곡선의 기울기 변화에 해당) 3. 유리전이 후의 팽창 4. plastic deformation

4. DMA (Dynamic Mechanical Analyzer; 동적기계분석기)



- 점탄성적 탄성도 (Viscoelastic Modulus) 측정
- Ageing (노후 테스트)
- Bending test (굴곡시험)
- Compliance (J^*)
- Compression test (압축하중 시험)
- Correlation avec chock
- Correlation with acoustic performances
- Correlation with materials formulation
- Correlation with products performances
- Creep behavior, Creep test
- Curing kinetics, Curing time
- Degree of reticulation
- Dimensional stability
- Dynamic test
- Dynamic viscosity (h^*)
- Fatigue test
- Gel time
- Glass transition temperature (유리전이온도, T_g)
- Humidity sensitivity

Impact resistance
Industrial products stiffness
Linear/Non-linear behavior (선형/비선형적 거동)
Damping, Loss angle (δ), Loss factor (손실계수, $\tan \delta$)
Mechanical properties (기계적 특성)
Melting point (용융점, T_m)
Morphology of polymers (고분자 형태학)
Optimization of curing process (경화과정의 최적화 검사)
Penetrometry test
Polymer compatibility
Prediction of long term mechanical behaviour
Relationships mechanical properties/molecular structure
Relaxation time
Reticulation follow up
Rheological properties
Secondary transitions
Shear modulus (G^*)
Shear test
Specimen stiffness
Stress relaxation test
Tension test
Thermal properties
Thermal stability
UV sensitivity
Viscoelastic properties
Young's Modulus E^*
Storage Modulus (저장탄성율, E' , G')
Loss Modulus (손실탄성율, E'' , G'')

그림 설명. DMA curve of a polymer : 비결정성 고분자의 DMA curve. T_g 온도에서의 유리전이(α). 더욱 낮은 온도에서 β -transition은 거대분자(macromolecule)중 측쇄(lateral group)의 "thawing(완화)"에 상당한다. Damping curve ($\tan \delta$)에 관한 최대값은 고분자 분자쇄의 분자 운동 (α - and β -transitions)을 나타낸다. 실제 유리전이인 β -transition 시 Young's Modulus, E 는 몇 단계에 걸쳐 감소한다.

5. 물리화학적 특성에 따른 열분석기 선택 가이드

Thermal properties/Instruments	DSC	TMA	TGA	DMA	TOA
Specific heat capacity	●				
Linear coefficient of expansion		●			
Viscoelastic behavior		●		●	
Young's and shear modulus, stiffness		●		●	
Damping behavior				●	
Heat of fusion	●				
Temperature of fusion (Melting temperature)	●	●		●	●
Enthalpy change, heat of transformation	●				
Melting behavior, liquid fraction	●	●		●	●
Purity of crystals (unpolymerized materials)	●		●		●
Temperature of crystallization	●				
Heat of crystallization	●				
Cold crystallization	●	●		●	
Evaporation, sublimation, desorption	●		●		●
Polymorphism (change of crystal modification)	●	●			●
Solid-Solid transformation	●	●			●
Mesophases in liquid crystals	●				●
Glass transition	●	●		●	●
Softening		●		●	●
Thermal decomposition, pyrolysis, depolymerization	●	●	●		●
Thermal stability	●	●	●		●
Oxidative decomposition, oxidative stability	●	●	●		
Chemical reactions such as polymerization or curing, polyaddition	●	●	●		
Reaction kinetic investigations and kinetic prediction	●		●		
Investigation of the safety	●				
Analysis of the composition (e.g. moisture, liquid components, ash)	●		●		

붉은 색 표시가 우세한 기기임을 표시함.

TOA는 Thermo-optical Analyzer (또는 Fusion point analyzer)로써 melting, boiling, cloud, softening, dropping point analyzer나 핫스테이지 (microscopic hotstage)을 일컫는다.

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