



# Shape Memory Phenomena and Functional Characterization of Shape Memory Alloys



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**SLS&OPTIROB 2024**

## **Shape Memory Alloys**

Shape memory alloys are thermoresponsive materials and take place a class of advanced functional materials by exhibiting dual memory characteristics, Shape Memory Effect and Superelasticity.

These phenomena are characterized by the recoverability of two certain shapes of material in reversible way at different conditions. These alloys are functional materials with these properties, and they used as shape memory devices in many fields from biomedical to the building industry.

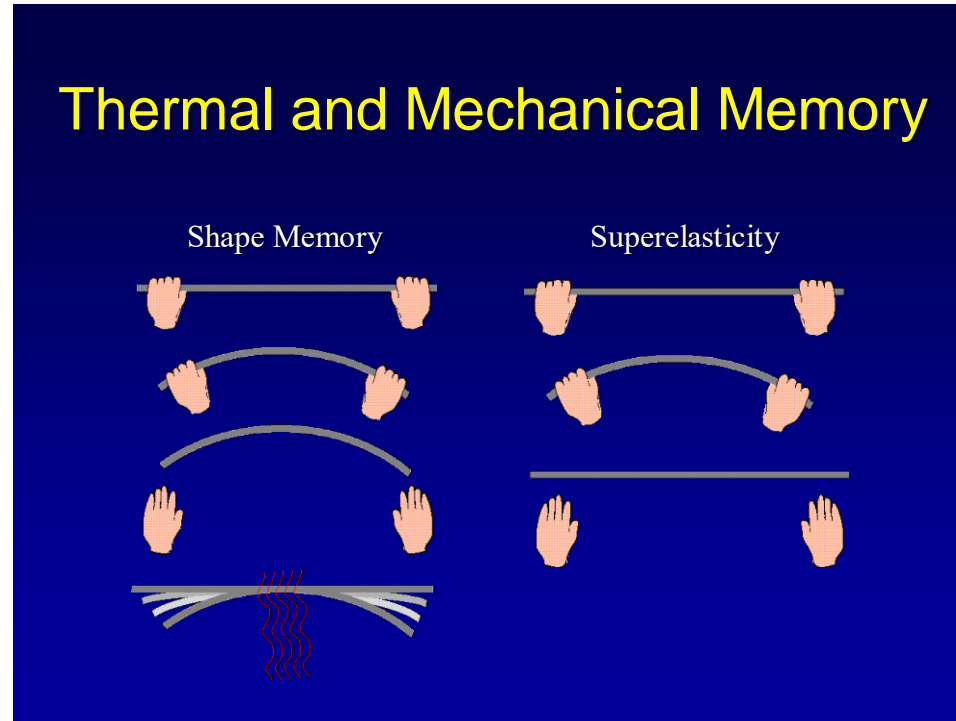
# Shape Memory Effect and Superelasticity

Shape Memory Effect is initiated with thermomechanical treatments, on cooling and deformation, and performed thermally on heating and cooling, with which shape of the material cycle between original and deformed shapes, in reversible way, and this behavior can be called Thermal Memory or Thermoelasticity.

This is plastic deformation, due to the soft character of material in low temperature condition, deformation energy is stored in the material and releases on heating by recovering the original shape.

These alloys exhibit another property, Superelasticity, which is performed with mechanically stressing and releasing the material in elasticity limit at a constant temperature in the parent phase region, and material recovers the original shape upon releasing, by exhibiting elastic material behavior. Therefore, this behavior can be called Mechanical Memory.

# Processing of SME and SE in bulk level

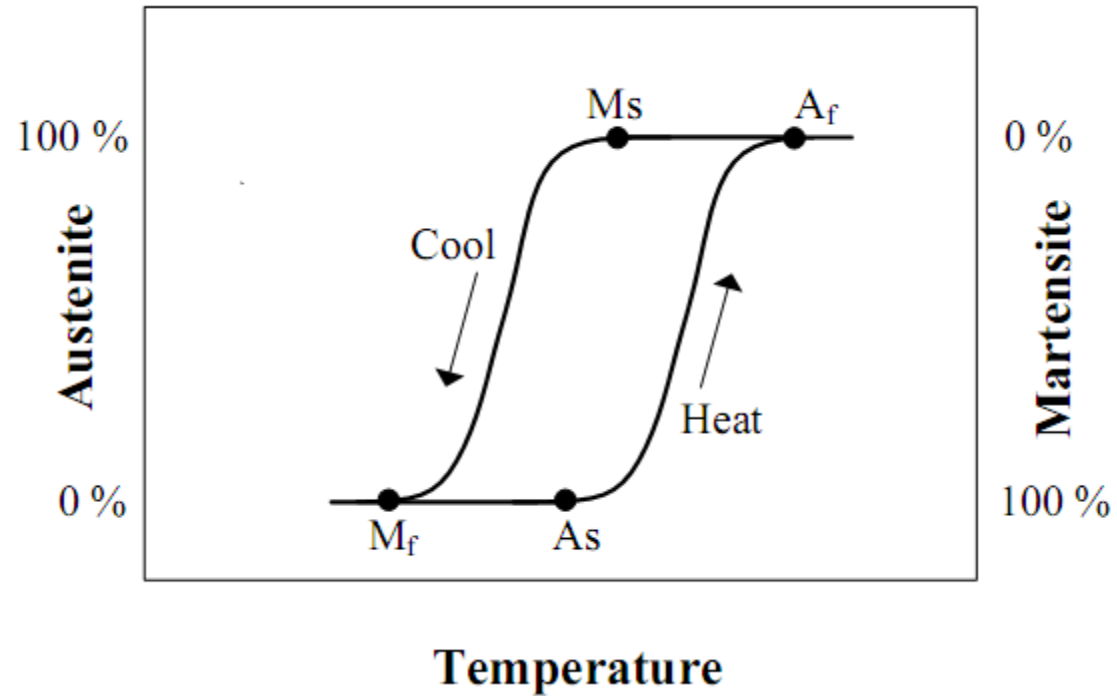


## Shape Memory Effect (SME) and Superelasticity (SE)

Shape Memory Effect is result of the crystallographic transformations, thermal and stress induced **martensitic transformations** and evaluated by the structural changes in atomic scale and crystallographic level.

Superelasticity is also result of stress induced martensitic transformation and performed with mechanically stressing and releasing in elasticity limit at a constant temperature in the parent austenite phase region.

# Temperature Hysteresis of Shape Memory Alloys



# SME, SE and Martensitic Transformations

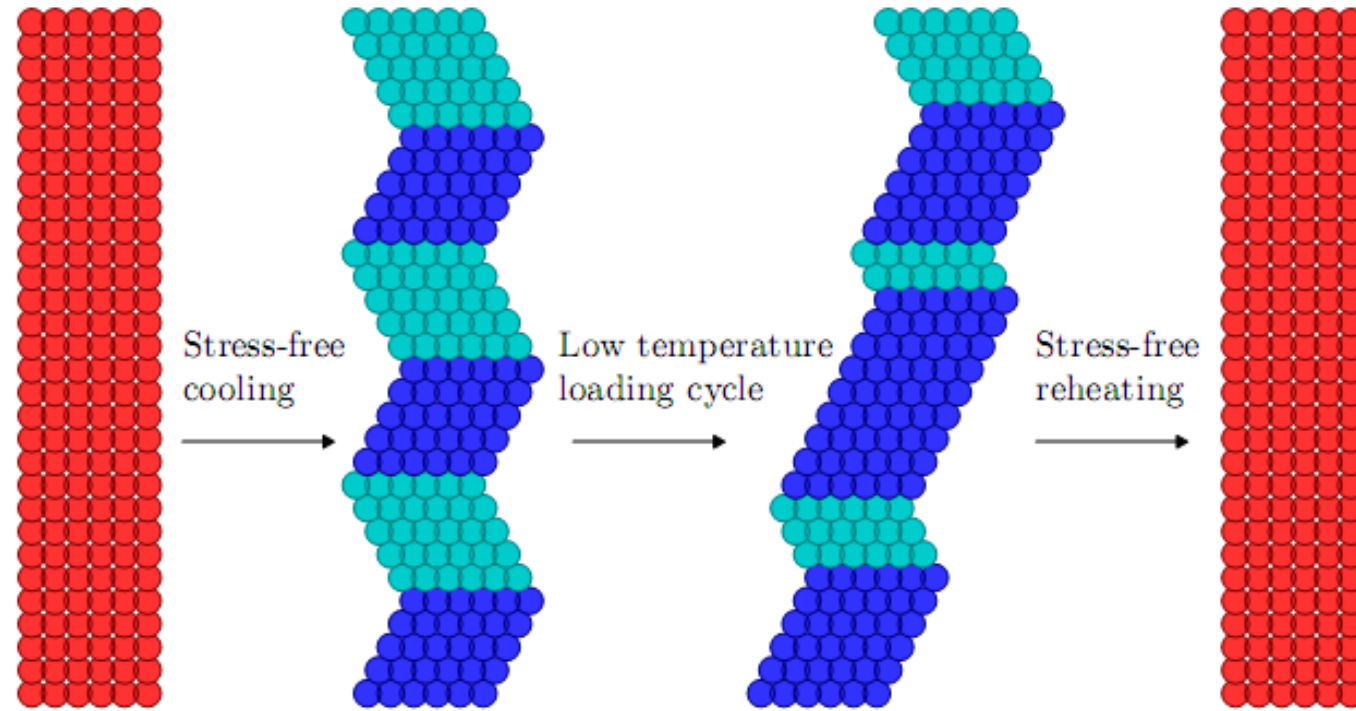
Shape memory behaviour is evaluated by the structural changes in atomic scale caused by internal stresses, and shape change occurs in bulk level. Shape memory effect is governed by the crystallographic transformations, thermal and stress induced martensitic transformations. Thermal induced martensitic transformations occur on cooling with cooperative movements of atoms in  $\langle 110 \rangle$ -type directions on the  $\{110\}$ -type planes of austenite matrix along with the lattice twinning reaction and ordered parent phase structures turn into twinned martensite structures. The twinned structures turn into detwinned martensite structures by means of stress induced transformation with deformation in the martensitic condition.

Superelasticity is also governed by stress induced martensitic transformation and ordered parent phase structures turn into detwinned martensite structure with stressing.

However, lattice twinning and detwinning reactions play important role in martensitic transformations.

## Schematic of Shape Memory Cycle

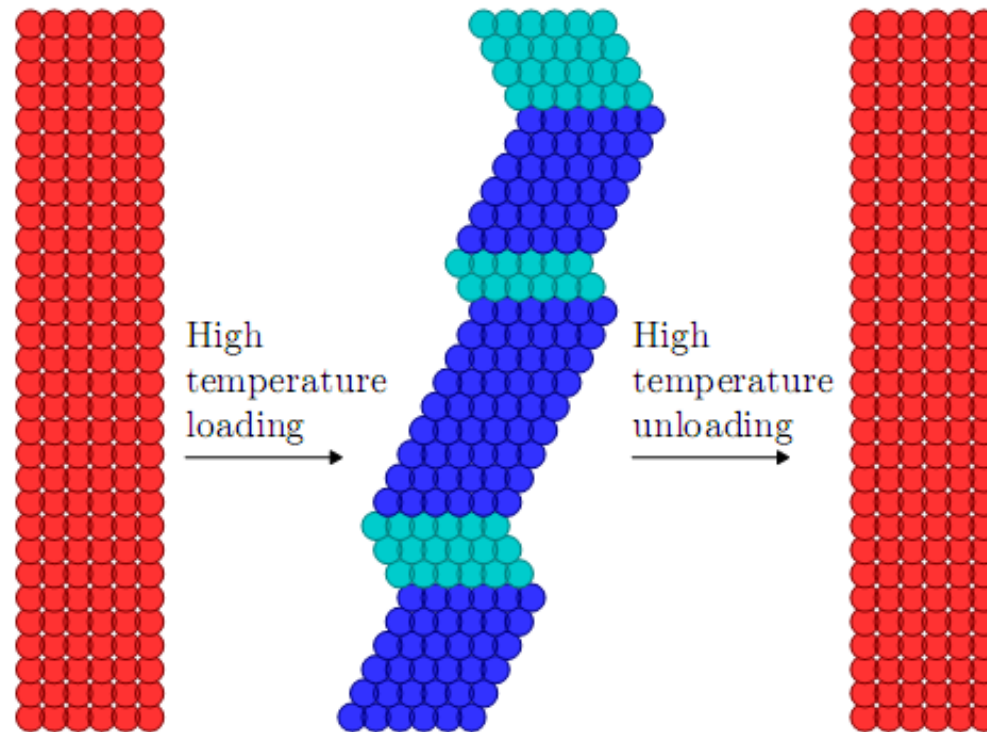
High symmetric ordered austenite phase structures turn into the twinned structures, martensite variants (blue and green), on cooling. Twinned martensite structures turn into the detwinned martensite structure, by means of stress induced martensitic transformation with stressing at low temperature. Detwinned martensite structures revert back to the ordered parent phase structures, by means of reverse austenitic transformation upon heating.





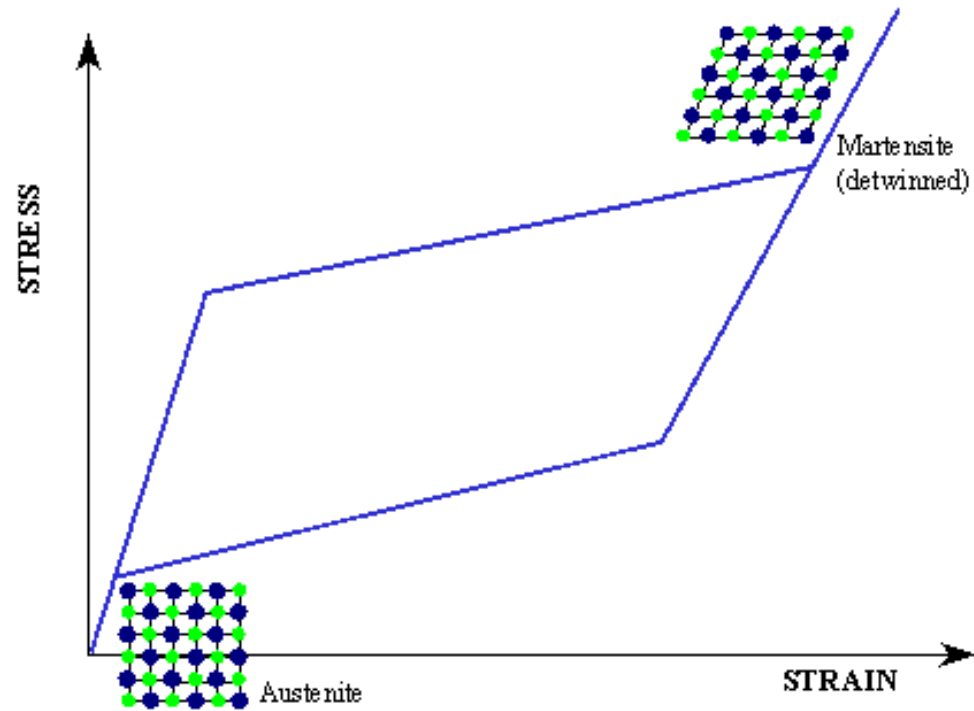
## Schematic of Superelasticity

Stressing of the material in high temperature parent phase region, parent phase can generate stress-stabilized martensite, which reduces the energy required to accommodate an applied deformation. Material structure turns into the ordered parent phase structure upon removing the stress.

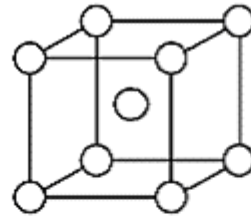


# Superelastic behaviour, and stress-strain diagram

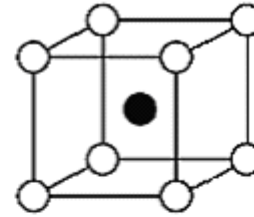
## Stressing and releasing paths in SE



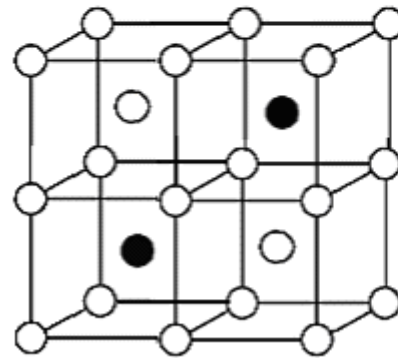
# Basic $\beta$ - phase structures



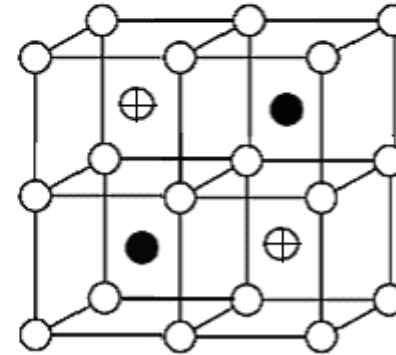
(a)



(b)



(c)



(d)

- ( a ) – Basic bcc ( A2) unit cell,
- ( b ) – CsCl -(B2) – type unit cell,
- ( c ) – Cu<sub>3</sub>Al - ( DO3 ) - type unit cell (half),
- ( d ) – Cu<sub>2</sub>AlMn - (L21 ) – type unit cell (half).

# Experimental

## Alloys

### 1. CuZnAl (Alloy 1)

Cu- 26.1%Zn - 4% Al ( in weight)

Cu- 24.2%Zn - 9% Al (in atomic)

$$M_s = 36 \text{ }^\circ\text{C} \text{ , } M_f = 30 \text{ }^\circ\text{C}$$

### 2. CuAlMn (Alloy 2)

Cu- 11.0%Al - 6% Mn ( in weight)

Cu- 22.4%Al - 6% Mn ( in atomic)

$$M_s = 133 \text{ }^\circ\text{C} \text{ , } M_f = 98 \text{ }^\circ\text{C}$$

$M_s$  ,  $M_f$  : Martensite start and finish temperatures.

Both alloys are fully martensitic at room temperature.

## **Thermal treatments**

Specimens obtained from these alloys were solution treated for homogenisation in the  $\beta$ -phase field as following and then quenched in iced-brine and aged at room temperature.

CuZnAl alloy: at 830°C for 15 minutes and quench in iced-brine.

CuAlMn alloy: at 700°C for 20 minutes and quench in iced-brine.

## **Powder specimens**

Powder specimens for X-ray examination were prepared by filling the alloys.

Powder specimens were sealed in evacuated quartz tubes and given  $\beta$ -phase homogenisation treatments:

CuZnAl alloy: at 830°C for 15 minutes and quench in iced-brine.

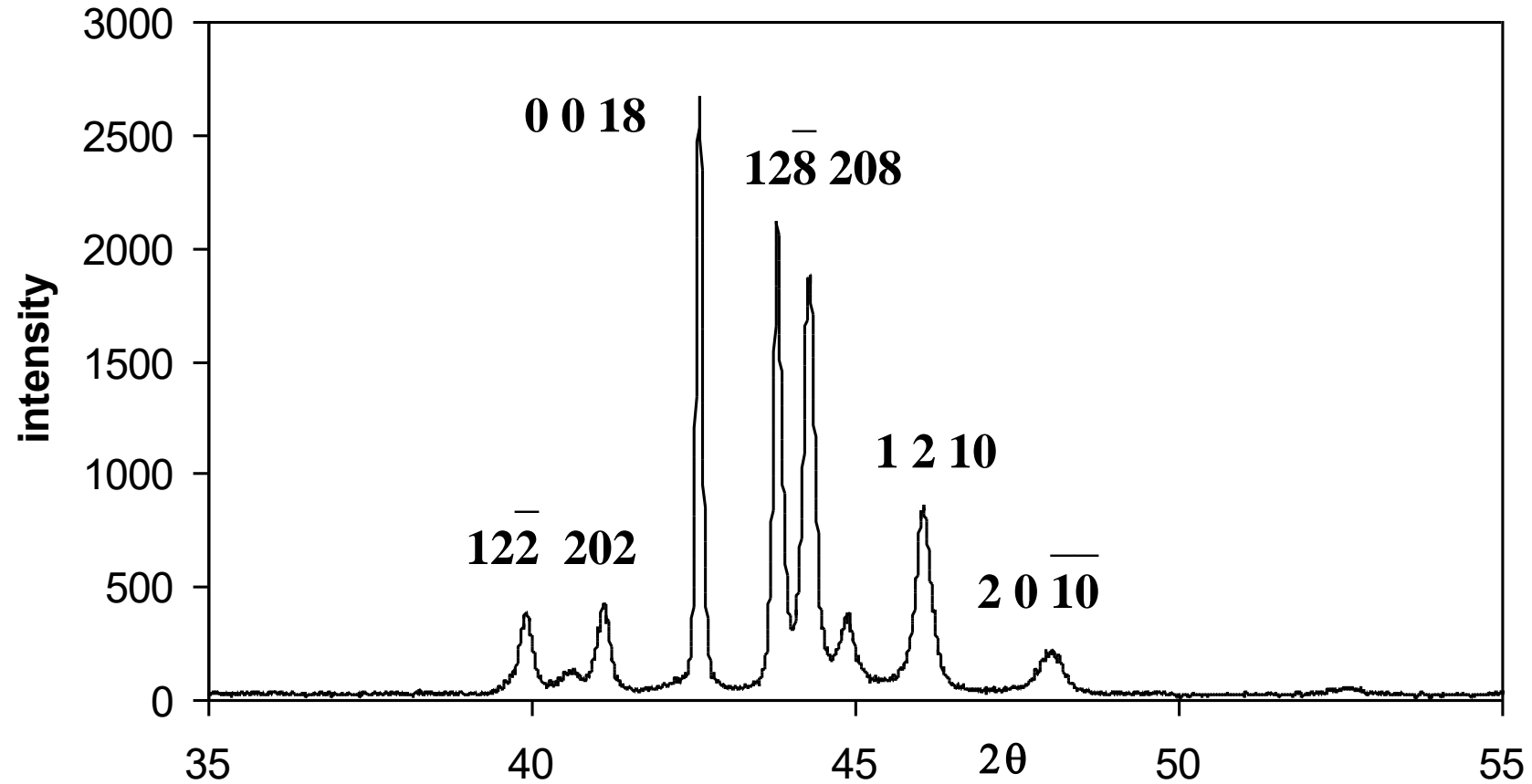
CuAlMn alloy: at 700°C for 15 minutes and quench in iced-brine.

Powder diffractograms were obtained for all the specimens at different stages of ageing in a long time interval.

# X-Ray diffractograms

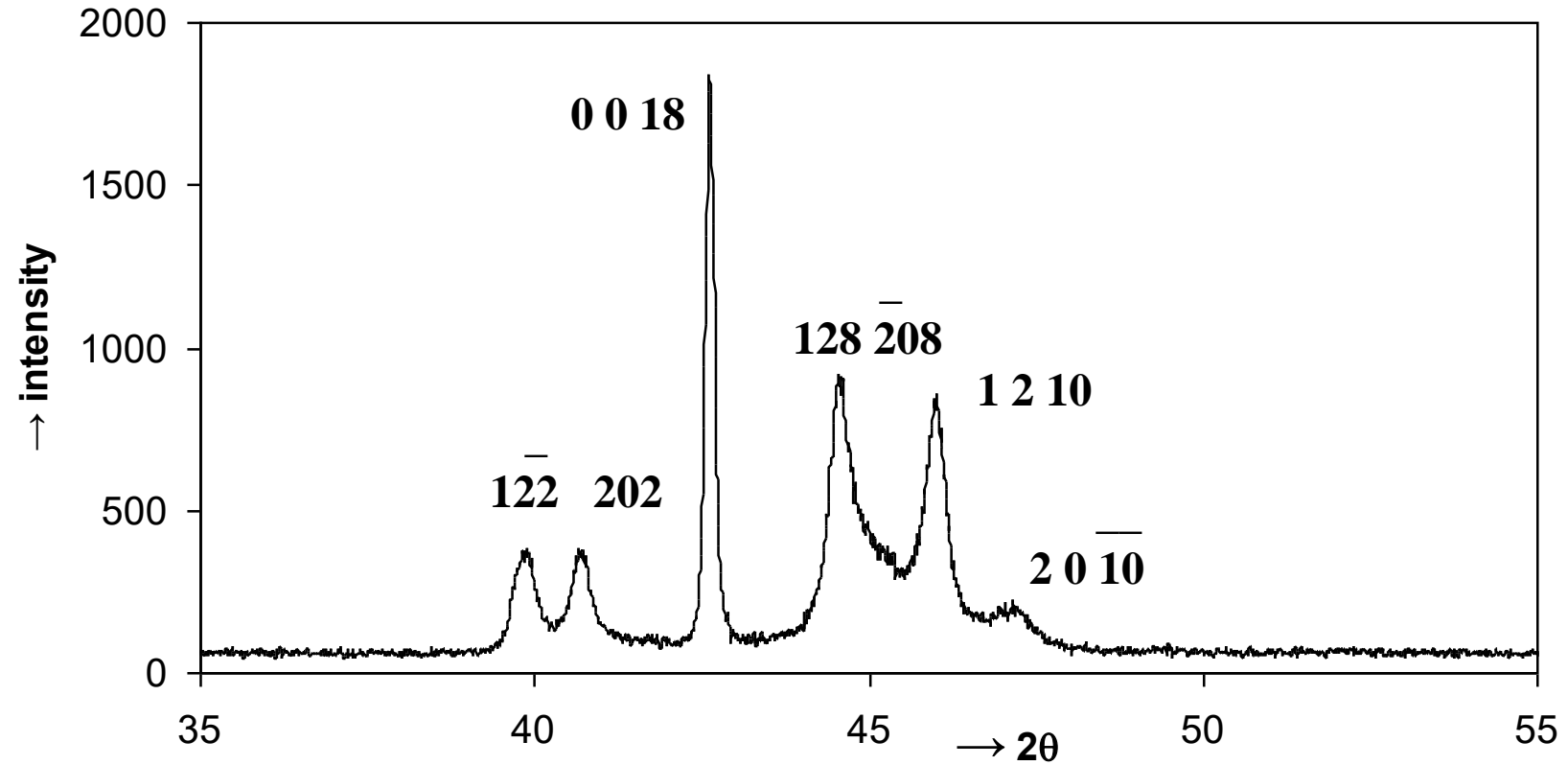
## 1. CuZnAl Alloy

Long-term aging at RT for about fifteen years after quenching



## 2. CuAlMn Alloy

Long-term aging at RT for about fifteen years after quenching



## Interplane relations

A series of x-ray diffractograms have been taken from both of the alloy samples in a long time interval, and some changes have been observed in diffraction angles and peak intensities and characteristics with aging duration.

In particular, some of the successive peak pairs have shifted toward each other. These successive peaks provide the following relation:

$$(h_1^2 - h_2^2) / 3 = (k_2^2 - k_1^2) / n$$

where  $n=4$  for 18R martensite.

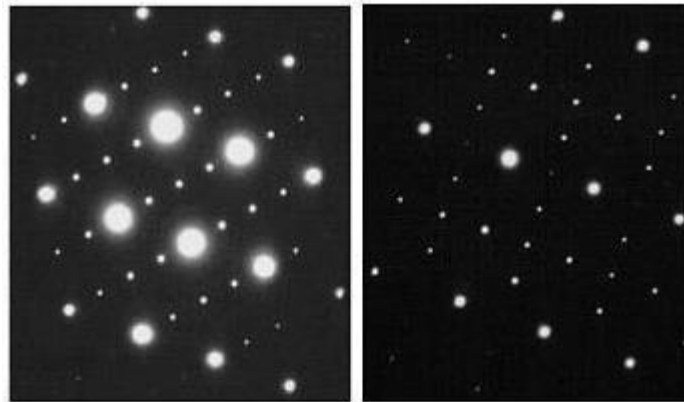
These plane pairs can be listed as follow for 18R structure; (122)-(202), (128)-(208), (1 2 10) – (2 0 10), (040)- (320).

At the long term investigation ( nearly 15 years), it is observed that these peak pairs come close each other with aging duration. These changes refer the changes in the crystal structure of the material.



## **Electron Diffractions**

Electron Diffractions patterns taken from CuZnAl and CuAlMn alloys also exhibit super-lattice reflection.



## Conclusions

Shape memory effect is evaluated by the structural changes in microscopic scale by means of martensitic transformation.

The fundamental structures of the  $\beta$ -type martensites are orthorhombic close-packed structures which consist of an array of close-packed planes in copper based SMAs.

The  $\beta$ -type martensites have the layered structures and are characterized by the stacking sequences depending on the order in parent phase.

Copper based ternary alloys have the DO<sub>3</sub> - type superlattice in parent austenite phase, and the following stacking sequence occurs with martensitic transformation; AB'CB'CA'CA'BA' BC'BC'AC'AB' (18R).

Based on austenite-martensite relation, the basal plane of 9R (or 18R) martensite originates from the {110}-type planes of the parent phase, on which lattice invariant shears occur in the <110>-type directions during the transformation.

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**The way we see it, physics has too many grey areas already.....**



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**If we knew what it was we were doing, it would not be called research, would it?**

Albert Einstein, 1879 - 1955  
1921 Nobel Prize Winner

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Thank you very much  
for your attention!

