



3 - 4 Kasım / November 2023

Sheraton Ankara Hotel & Convention Center

Tudoksad Akademi **3. Ulusal Döküm Kongresi / 3rd National Foundry Congress** by Tudoksad Academy

FNSS

Savunma Sanayiinde Döküm Teknolojisi Alanındaki Yeni Trendler

Barış ÇETİN

FNSS Savunma Sistemleri AŞ, Ar-Ge Merkezi

Ankara Sheraton Hotel - 03/11/2023

HİZMETE ÖZEL

Brief Intro of FNSS



51 %

49 %



BAE SYSTEMS

817

- Founded : 1988
- Total Closed Area : 250.000 m²

Savunma Sanayiinde Döküm Uygulamaları



Savunma Sanayii Gereklilikleri



Kompleks ve büyük ebatlı tasarımlar
(Ebat – üretim yöntemi ilişkisi)



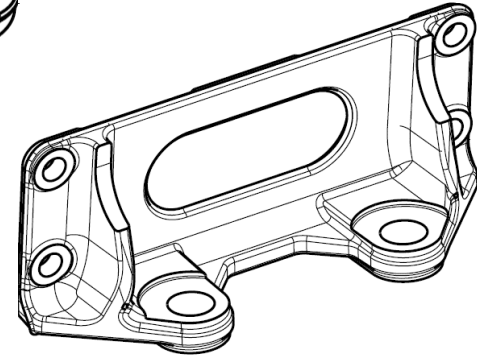
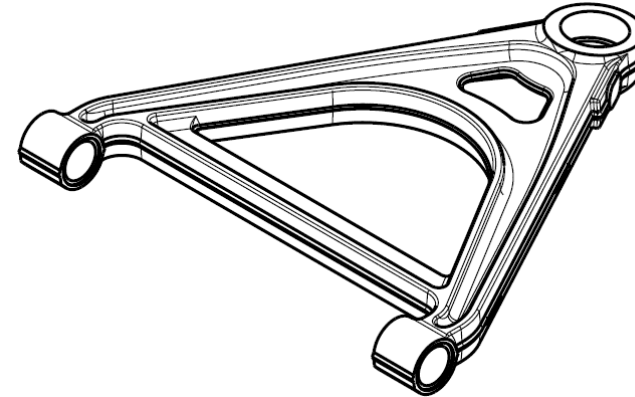
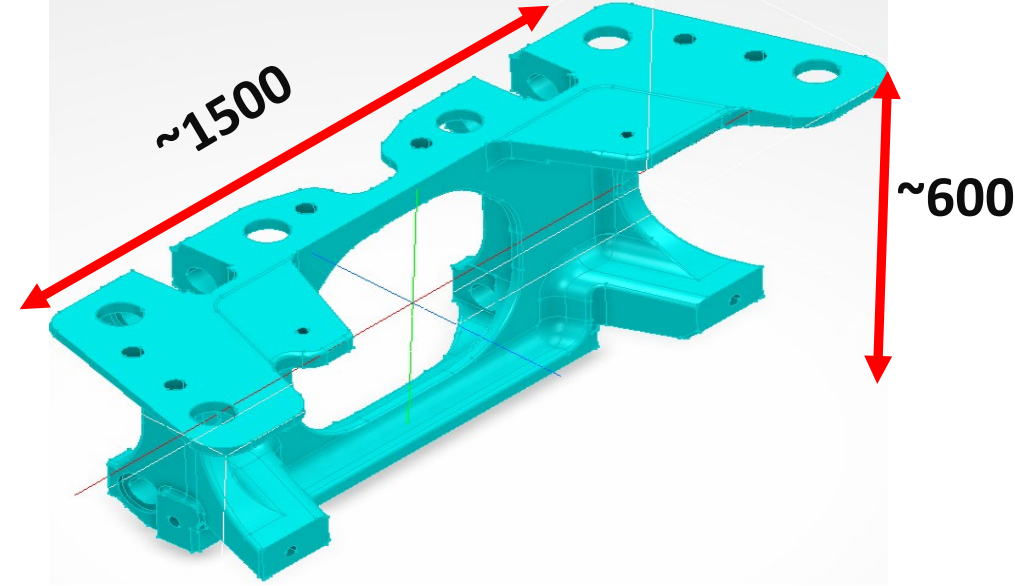
Yüksek mekanik performans ve güvenilirlik isterleri
(Harbe hazırlık oranı)



Düşük hacimli üretim
(müşteri özel tasarım – azalan ihtiyaç adedi)



Bu gereklilikler göz önüne alındığında döküm malzemelerden vazgeçilmesi pek olası görülmemektedir.



Savunma Sanayiinde Döküm Uygulamaları



Savunma sanayi uygulamaları özelinde balistik koruma ve/veya mayın koruma kabiliyetleri de geliştirilmiş olan döküm malzeme kullanımı söz konusu olabilmektedir.



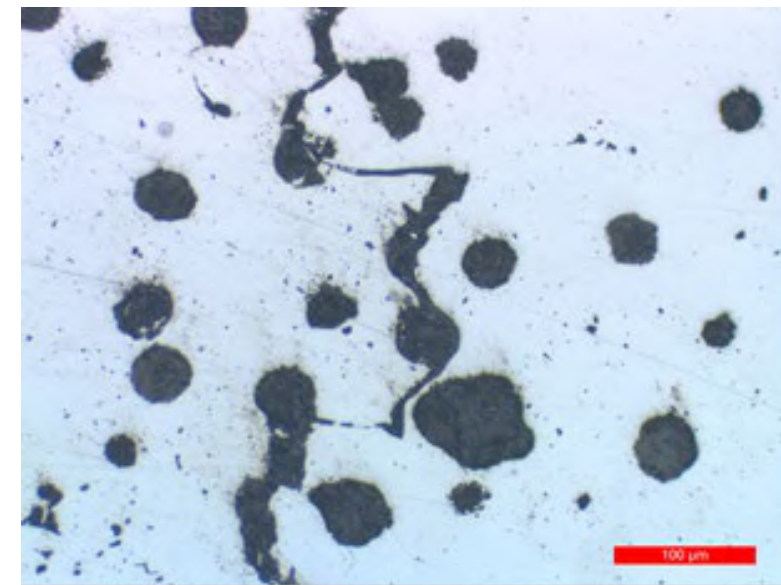
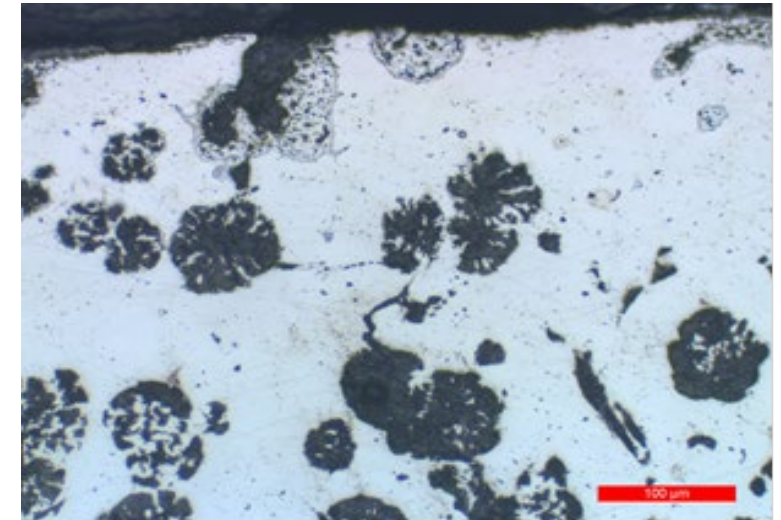
TOKLUK

Vs.

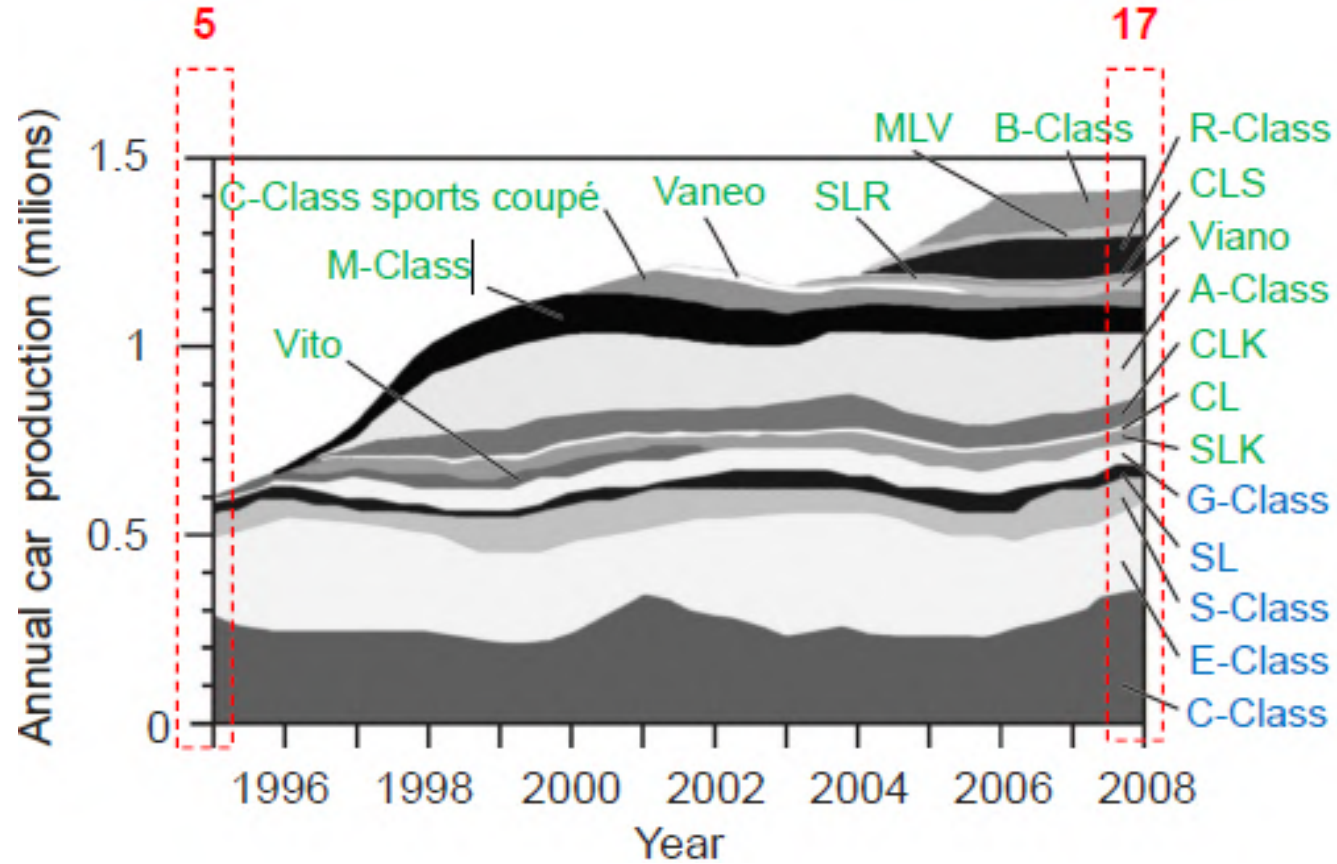
BALİSTİK DAYANIM



Balistik Döküm Plakalar



İmalat Sanayiinde Genel Eğilim



*Döküm malzemeler özelinde
de daha esnek üretim
yöntemleri mümkün mü?*

3B Yazma – Min. model yatırımı

Ürün Çeşitliliği



Tasarım İşçiliği

Prototip İhtiyacı!!!



Tasarım / Üretim Hacmi



Geliştirilmiş Mekanik Özellikler

*En iyilenmiş alaşım ve ısı işlem çözümleri
(Fonksiyonel tasarım, ileri analiz kabiliyeti)*



İnsansız Muharebe Araçları



Hibrit operasyon



*Yüksek manevra kabiliyeti,
Ağırlık/beygir gücü oranı*

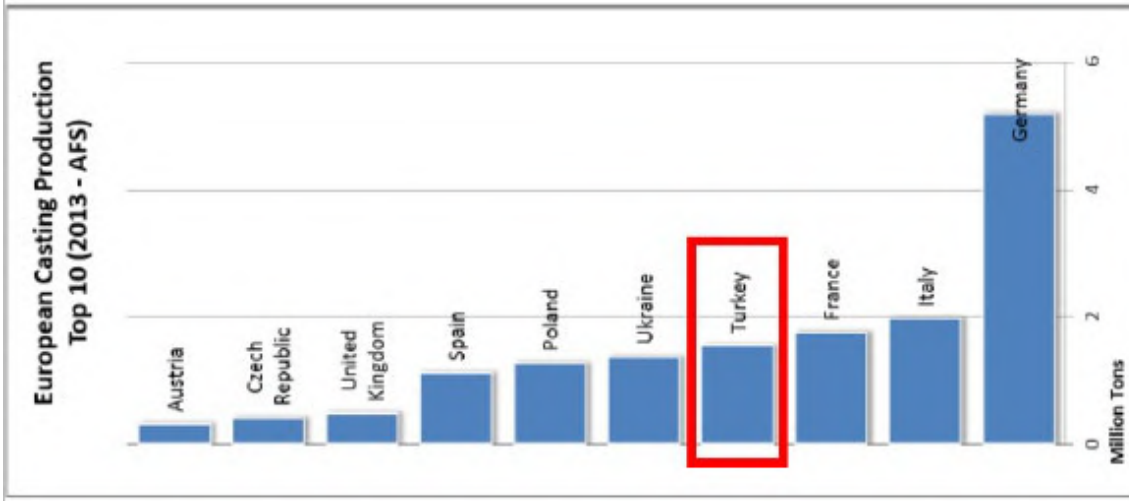


Sessiz operasyon

Küçük ebatlı üretim, yüksek

harbe hazırlık oranı





Avrupa Döküm Sektör Sonuçları

	2013	2014	2015 (I)	2016 (II)	%Δ (II/I)	Pay (%)
Çin	779,0	822,8	803,8	808,4	0,6	50,4
Japonya	110,6	110,7	105,2	104,8	-0,4	6,5
Hindistan	81,2	87,3	89,4	95,6	6,9	6,0
ABD	86,9	88,2	78,8	78,6	-0,3	4,9
Rusya	68,7	71,5	70,9	70,8	-0,1	4,4
Güney Kore	66,1	71,5	69,7	68,6	-1,6	4,3
Almanya	42,6	42,9	42,7	42,1	-1,4	2,6
Türkiye	34,7	34,0	31,5	33,2	5,3	2,1
Brezilya	34,2	33,9	33,3	30,2	-9,3	1,9
Ukrayna	32,8	27,2	23,0	24,2	5,2	1,5
Dünya	1.606,0	1.669,9	1.620,9	1.604,0	-1,0	100,0

Dünya Çelik Üretim sonuçları

- 2017 yılında demir çelik sektöründe toplam **~ 16,4 milyon ton** ithalat yapıлып karşılığında **~16 milyar USD** bedel ödenmiştir.
- 2017 yılında demir çelik sektörünün ihracatı ise toplam **~ 18,3 milyon ton** olup karşılığında **~13,4 milyar USD** gelir elde edilmiştir.



Yüksek katma değerli ürünlere geçiş





Döküm Malzeme Ar-Ge Gerekliliği

Posiz. Provini Sample Position (1)	Dimensione dei Provini Sample Dimension ø mm	Resistenza Rm Tensile Strength N/mm ²	Snervamento Rp 0.2 % 0.2 % Yield Strength N/mm ²	Allungamento A% Elongation	FIS		Resistenza Joule Impact Energy Media	Temperatura di Prova Testing Temper. °C
					Min	Max		
A	7	1210	947	10,8	331	343		

(1) A: Provino ricavato dal Getto Ø=7mm L=35mm. B: Provino colato a parte UNI ISO 1003/1563 Lynchburg sample Ø=14mm L=70 mm (D: Ø12.5 L=50mm). C: provino colato a parte UNI 5907 Ø=20mm
(1) A. Sample cut from the casting Ø=7mm. B. Casted sample separately following UNI ISO 1003/1563 Lynchburg sample Ø=14mm L=70 mm (D: Ø12.5 L=50mm). C. Casted sample separately following UNI 5907

ANALISI CHIMICA % Chemical Analysis %					
C	Si	Mn	P	S	Mg

ADI parts purchased from Europe → Chemical composition is not shared !!!

The composition of armor steel “ArmoX 500T” can be found via Google®



Chemical Composition (ladle analysis)

C ¹⁾ (max %)	Si ¹⁾ (max %)	Mn ¹⁾ (max %)	P (max %)	S (max %)	Cr ¹⁾ (max %)	Ni ¹⁾ (max %)	Mo ¹⁾ (max %)	B ¹⁾ (max %)
0.32	0.4	1.2	0.015	0.010	1.01	1.81	0.7	0.005

The steel is grain-refined. ¹⁾ Intentional alloying elements.

2 IRAD + TUBITAK 1507

+

TUBITAK 1707 Projesi



Hesaplamaalı Metalürji Yaklaşımları

Samples	C (wt.%)	Si (wt.%)	Mn (wt.%)	Cu (wt.%)	Ni (wt.%)	Mo (wt.%)	Austenitization Temp. (°C)	Austenitization Time (Min.)	Austempering Temp. (°C)	Austempering Time (Min.)
ADI-1	3.6	2.5	0.35	0	0	0	925	60	350	90
ADI-2	3.6	2.5	0.35	0	0	0	925	60	400	120
ADI-3	3.6	2.5	0.35	0.8	0	0	925	60	350	90
ADI-4	3.6	2.5	0.35	0.8	0.4	0.4	925	60	350	90
ADI-5	3.6	2.5	0.35	0.8	1	0.25	925	60	350	90

Tüm faz dönüşümleri için denge durumu varsayımı kullanılmıştır



Hesaplama Metalürji Yaklaşımları

<i>Before Heat Treatment</i>		ADI-1	ADI-2	ADI-3	ADI-4	ADI-5	<i>After Heat Treatment</i>		ADI-1	ADI-2	ADI-3	ADI-4	ADI-5
Thermocalc Calculations							Thermocalc Calculations						
Samples	C (wt.%)	Si (wt.%)	Mn (wt.%)	Cu (wt.%)	Ni (wt.%)	Mo (wt.%)	Austenitization Temp. (°C)	Austenitization Time (Min.)	Austempering Temp. (°C)	Austempering Time (Min.)			
M6C_E93 (vol.%) ADI-1	3.6	2.5	0.35	0	0.55	0.32	925	60	350	90	0.34	0.05	0.05
ADI-2	3.6	Real Experiment Data					925	60	Real Experiment Data			120	
Graphite (vol.%)	11.55	11.23	10.98	10.66	10.90			8.65	10.18	7.40	11.95	11.31	
ADI-3 BCC-alpha (vol.%)	3.6	2.5	0.35	0.8	0	0	925	60	350	90	88.45	88.77	89.02
ADI-4	3.6	2.5	0.35	0.8	0.4	0.4	925	60	350	90	41.1	32.4	32.5
ADI-5	3.6	2.5	0.35	0.8	1	0.25	925	60	350	90	22.3	20.5	

<i>New System with Carbon</i> C_{zero}	ADI-1	ADI-2	ADI-3	ADI-4	ADI-5
Thermocalc Calculation					
Bainite Start (2%) (Min.)	17.71	4.53	15.92	21.17	25.96

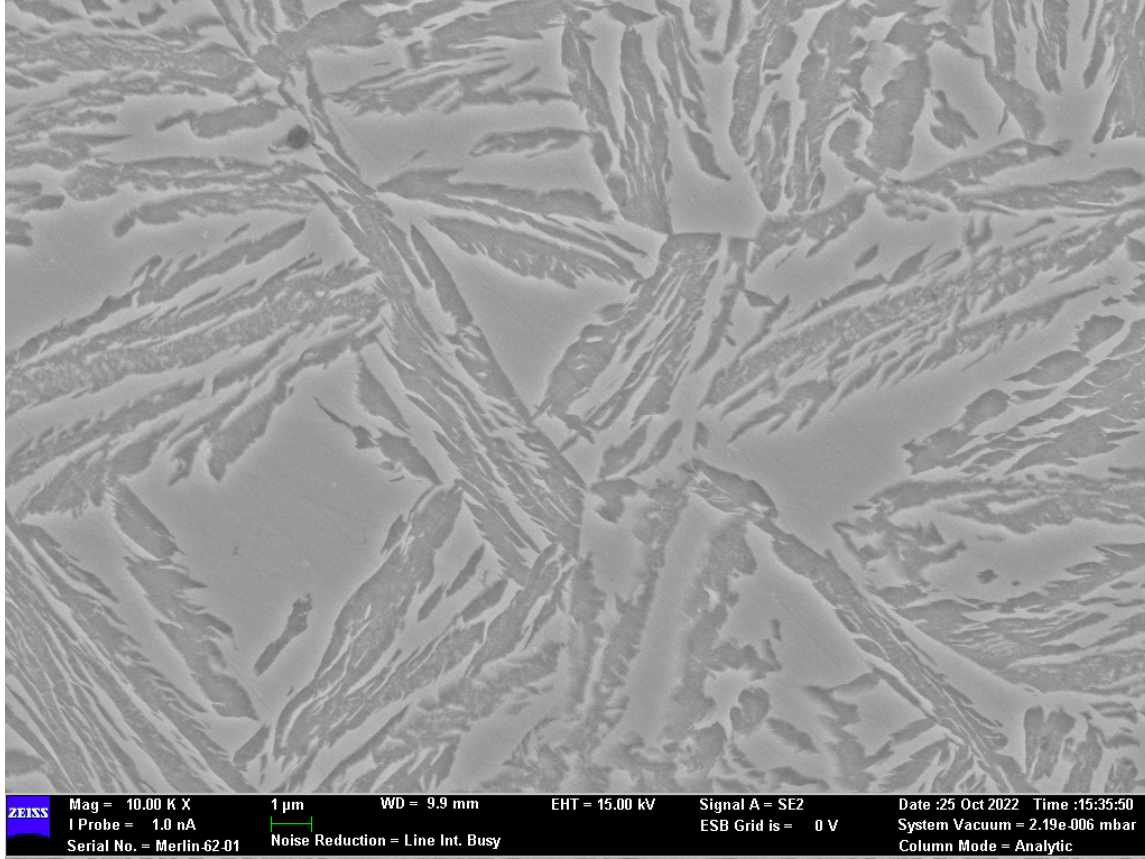
Ar-Ge Çalışmaları ve Meknaik Sonuçlar



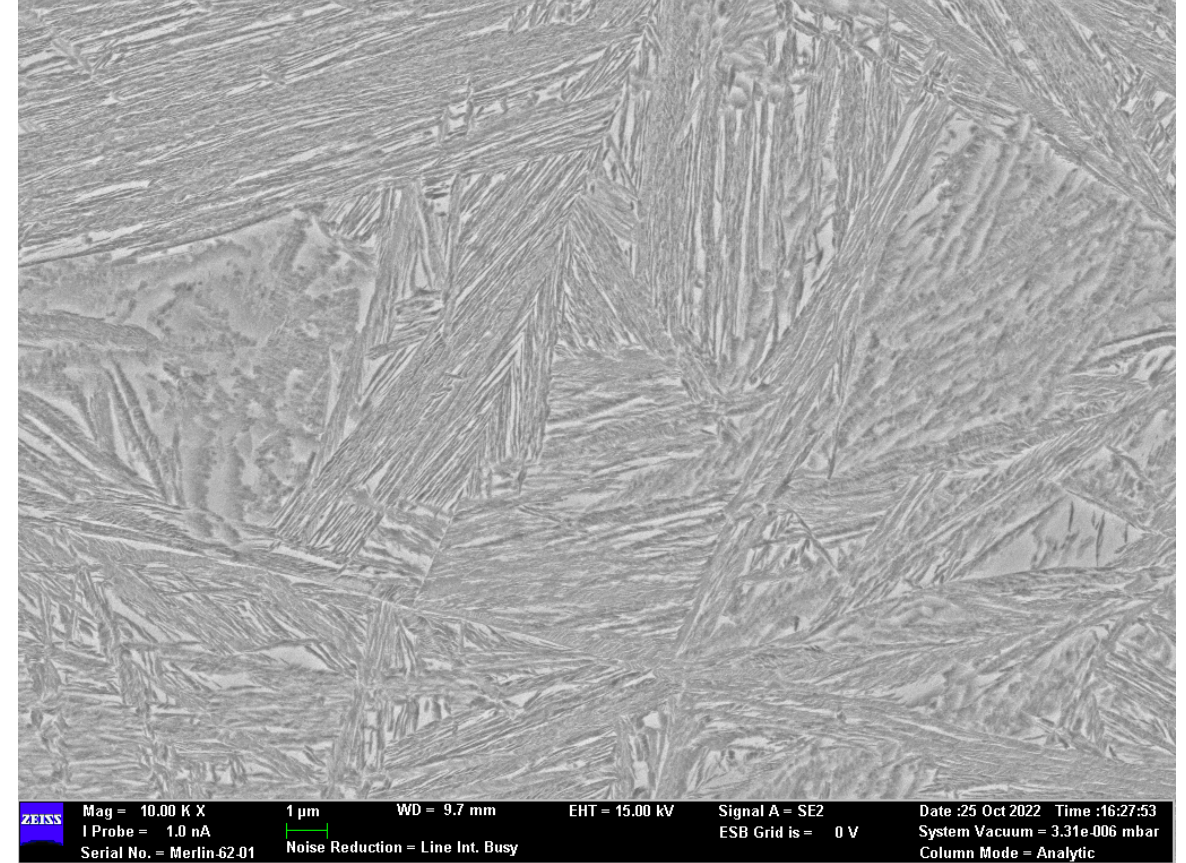
	Proses	SERTLİK (HB)	AKMA (MPa)	ÇEKME (MPa)	UZAMA (%)	
Alaşım B (%1 Ni)	PROSES -4 (350°C, 2 Saat)	360	798	1060	8,5	79
Alaşım C (%2 Ni)	PROSES -6 (350°C, 3 Saat)	285	756	1003	9	107,04
Alaşım B (%1 Ni)	PROSES -5 (250°C, 24 Saat)	510	1273	1396	3	60
Alaşım C (%2 Ni)	PROSES -7 (225°C, 36 Saat)	499	1704	1705	1,8	40,97



Mikro-yapı Analizleri



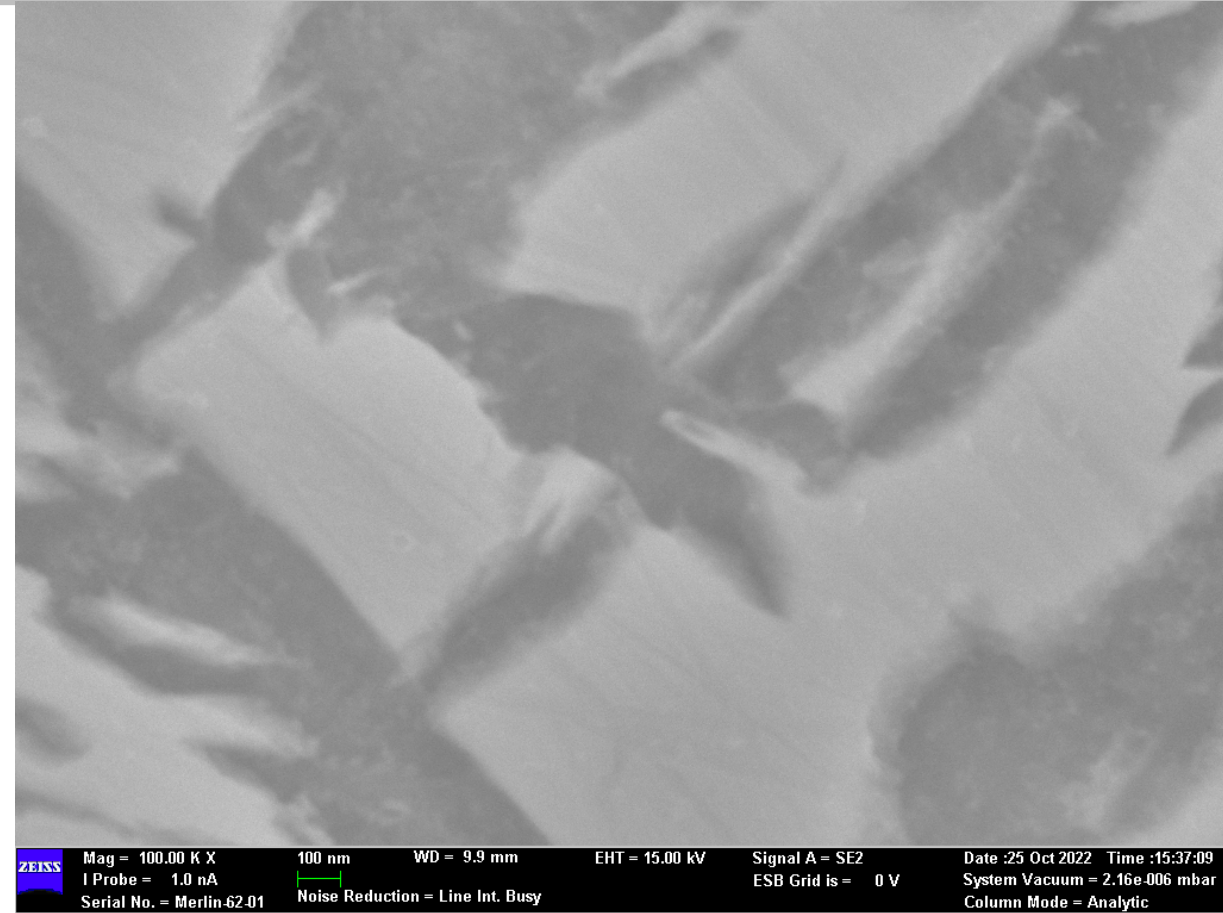
ÖSD-1 x10000



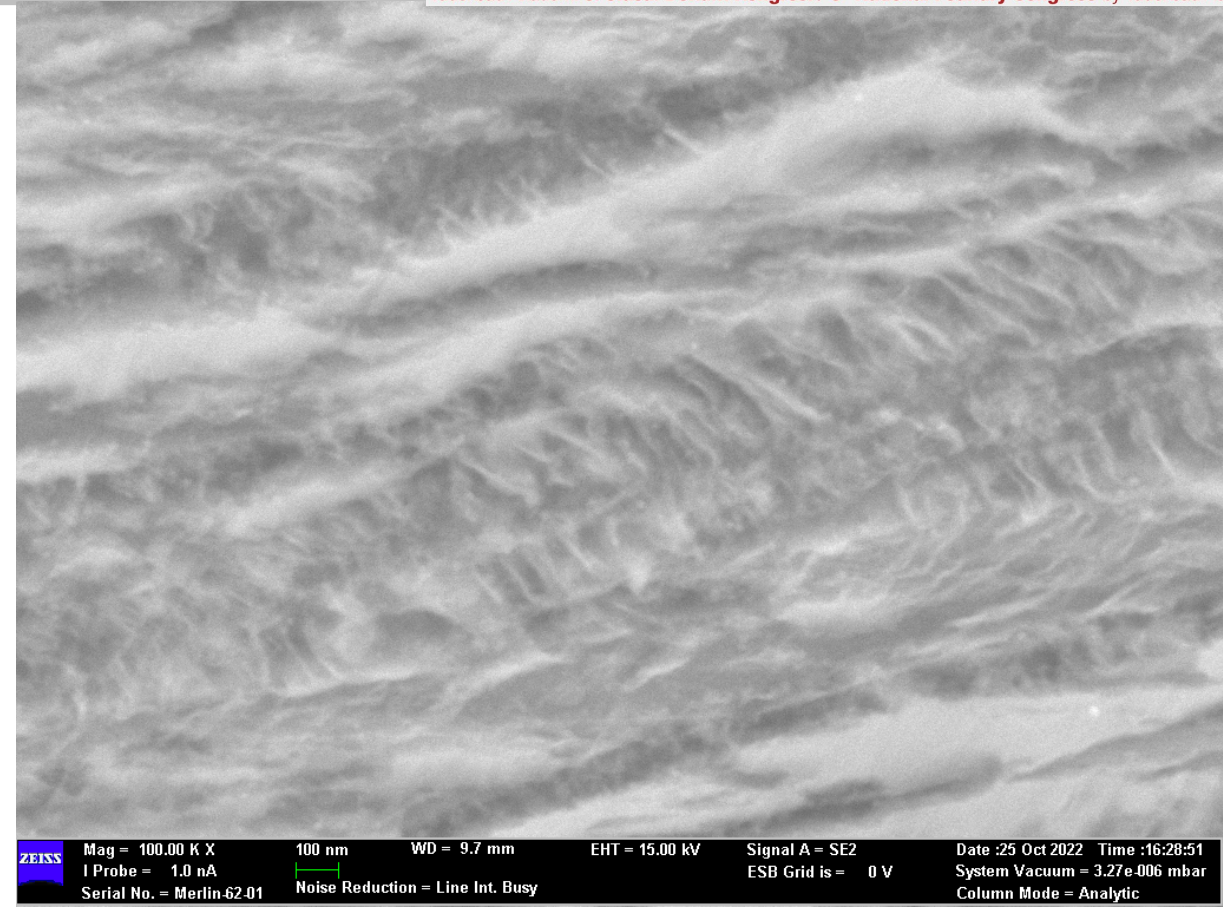
ÖSD-2 x10000



Mikro-yapı Analizleri



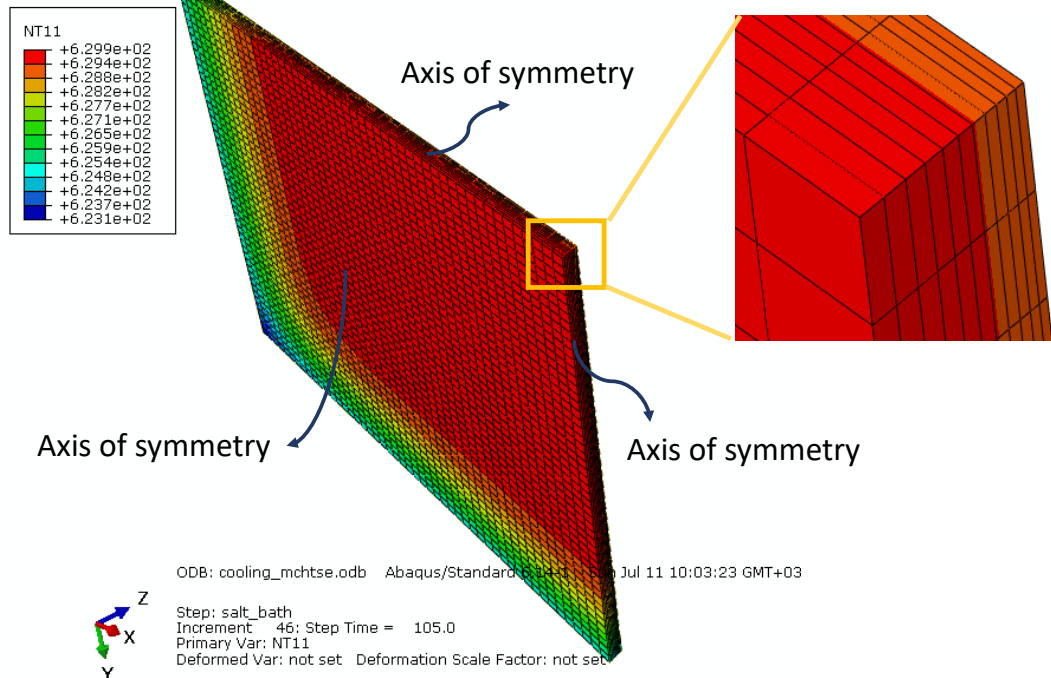
ÖSDD-1 x100000



ÖSDD-2 x100000

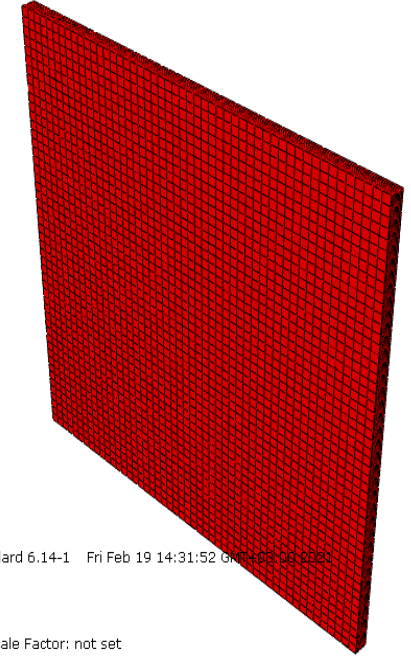
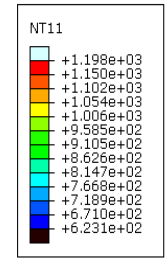


Isıl İşlem Bazlı Hesaplamalı Çalışmalar



C	Si	Mn	Cu	Ni	Fe
3,90	2,90	0,30	0,40	0,15	Balance

Plate: 500*500*16 mm



Step: salt_bath Frame: 0
Total Time: 0.000000

1/8 symmetric model

Implicit time integration

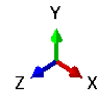
Temperature dependent properties

45 sec. air convection

$5 \text{ W/m}^2 \cdot \text{K}$

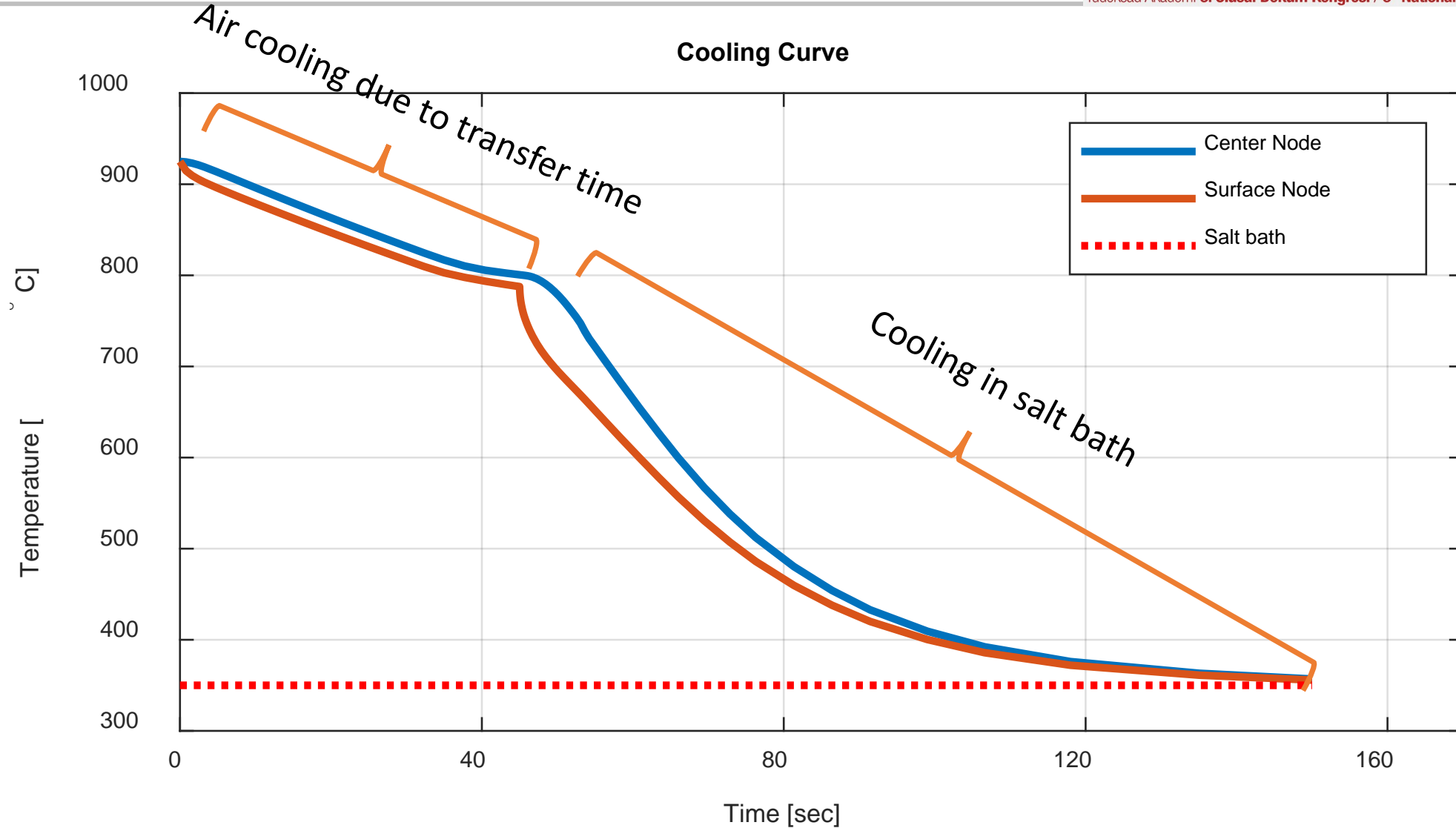
Salt bath

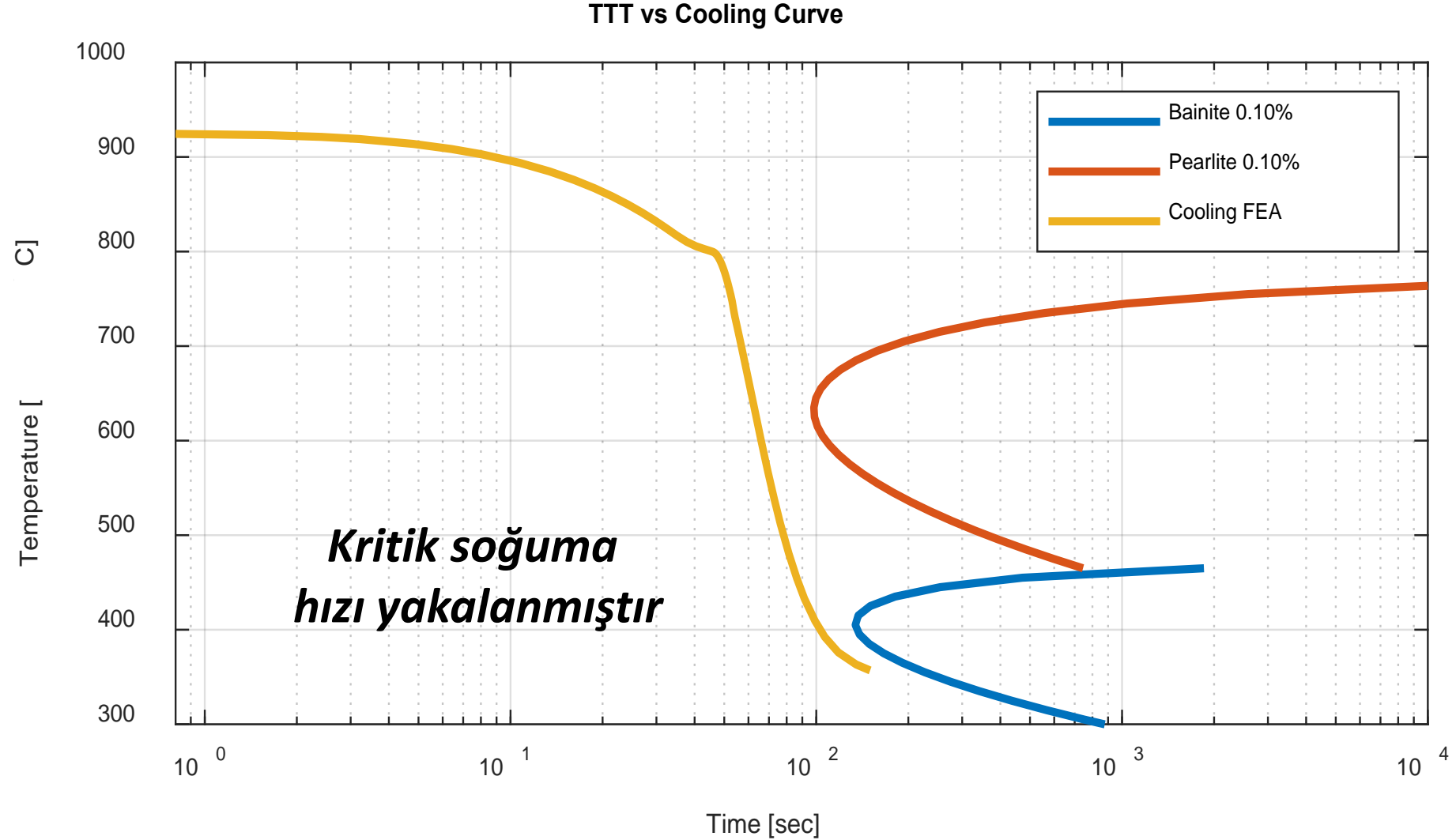
$2000 \text{ W/m}^2 \cdot \text{K}$



ODB: adi_saltbath.odb Abaqus/Standard 6.14-1 Fri Feb 19 14:31:52 GMT+03:00 CEST

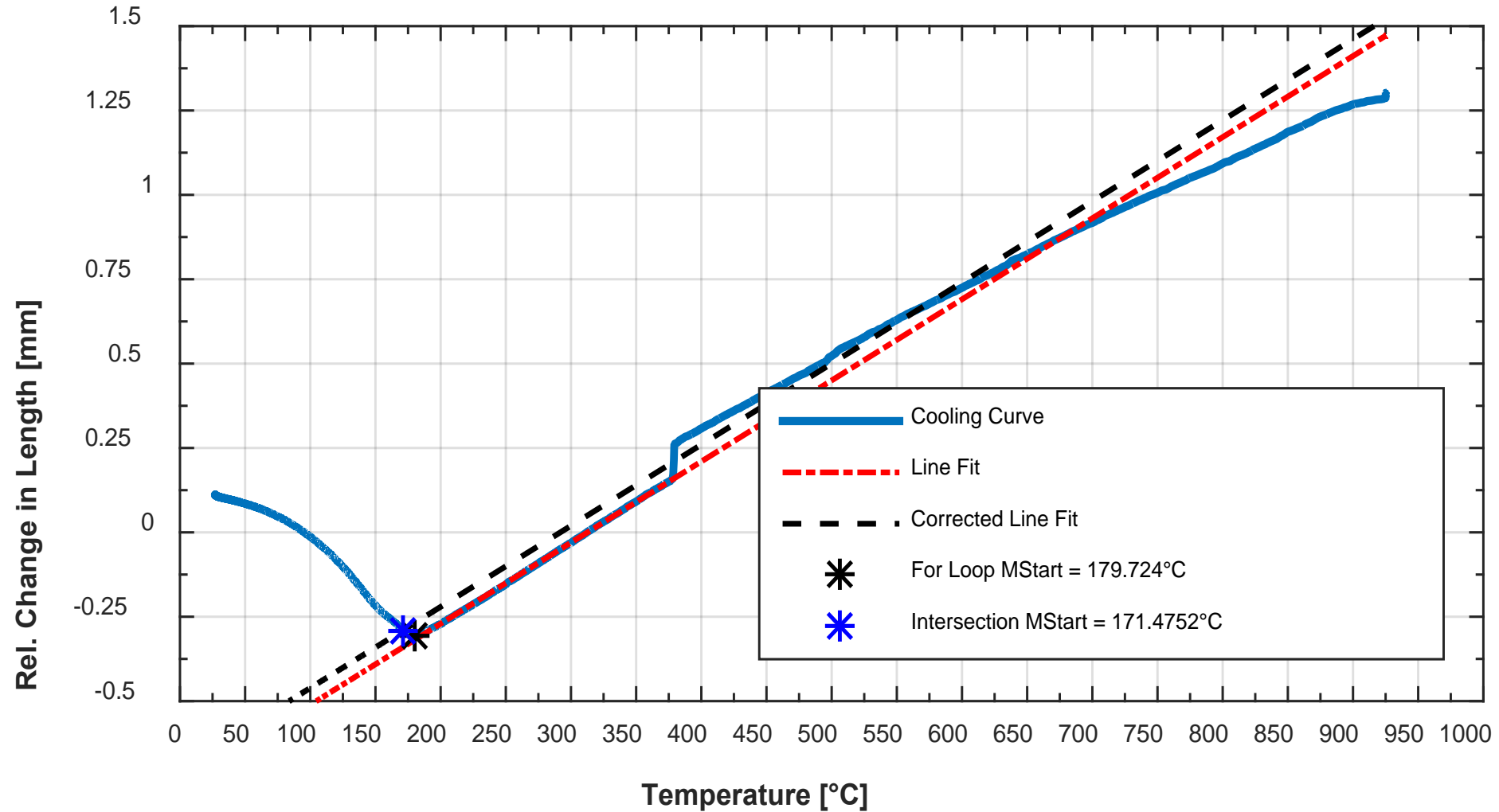
Step: salt_bath
Increment: 0; Step Time = 0.000
Primary Var: NT11
Deformed Var: not set Deformation Scale Factor: not set



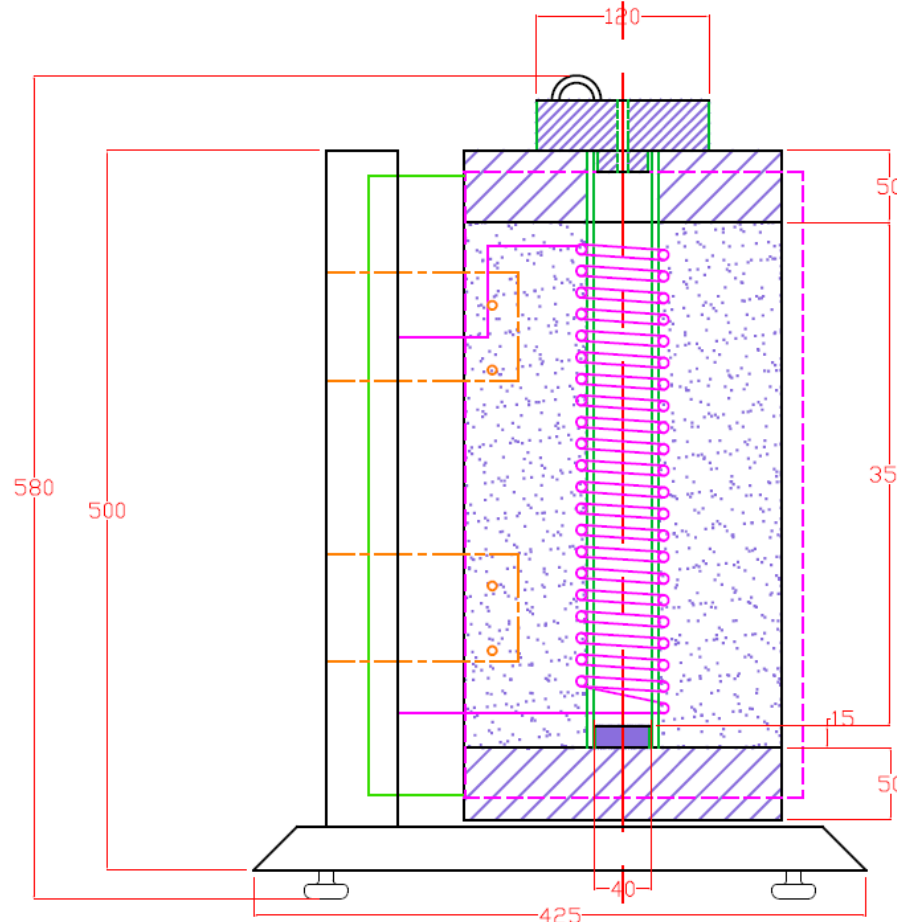
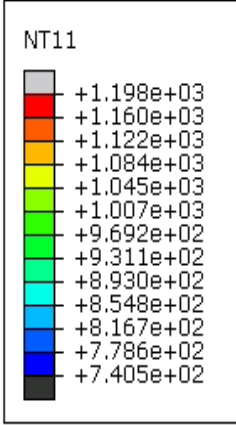




Cooling Curve of Sample-3

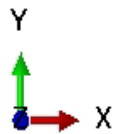
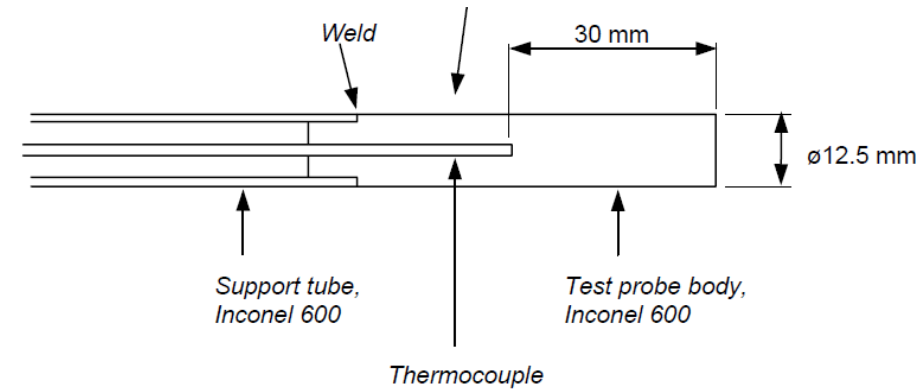


HTC Tespiti ile İlgili Deneysel Çalışmalar



Step: Step-1 Frame: 0
Total Time: 0.000000

Technical data sheet – standard test probe



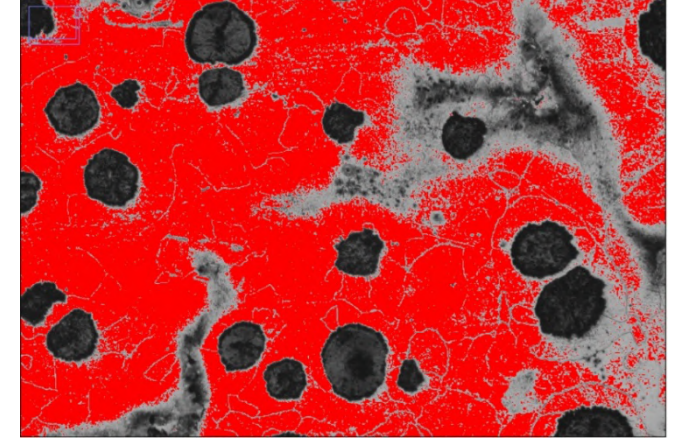
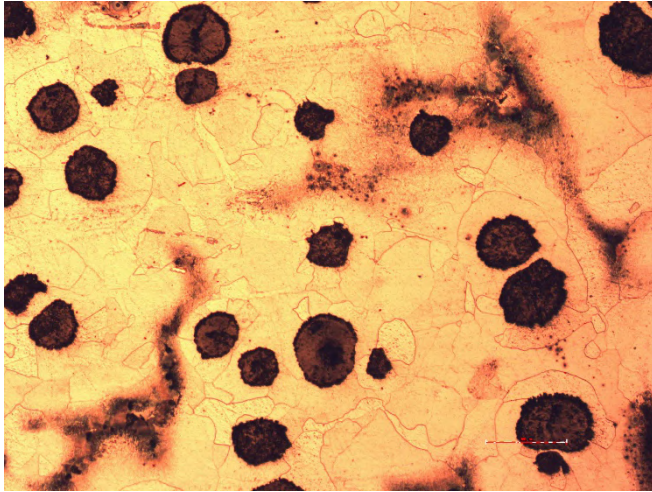
ODB: probe_cool.odb Abaqus/Standard 0.17.1 30/10/2023 10:20:37 GMT+03:00 2023

Step: Step-1
Increment: 0; Step Time = 0.000
Primary Var: NT11
Deformed Var: not set Deformation Scale Factor: not set

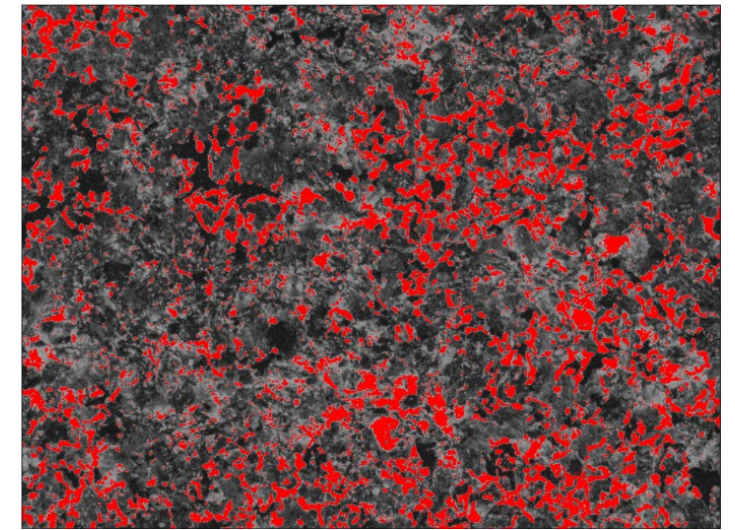
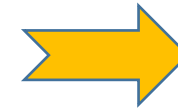
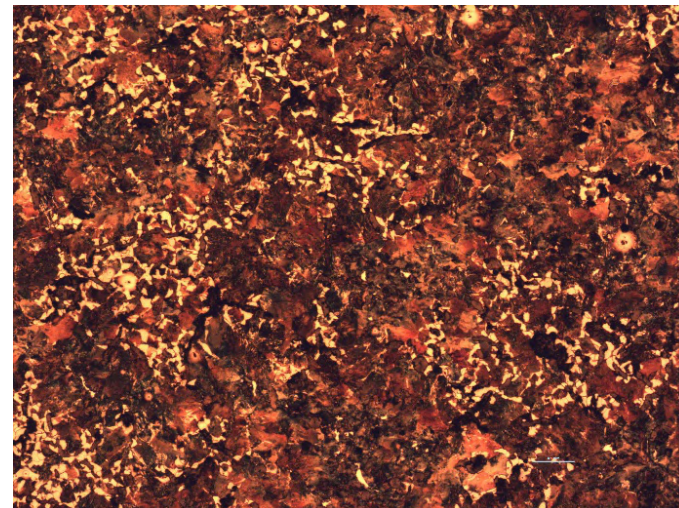
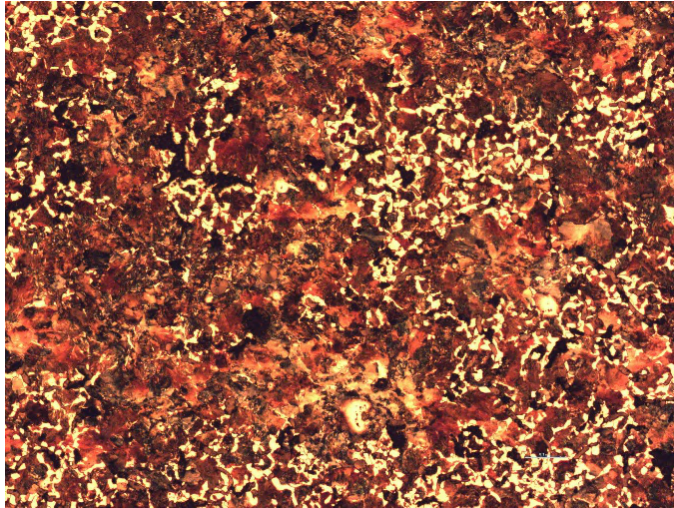


Niceliksel Metalografi Çalışmaları

ImageJ Yazılımı ile
Görüntü İşleme İmkanları

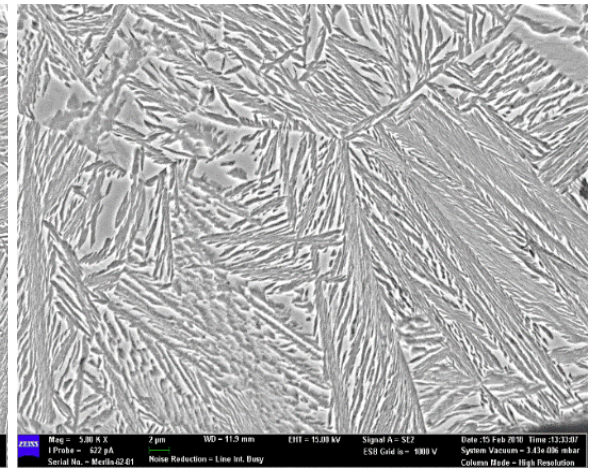
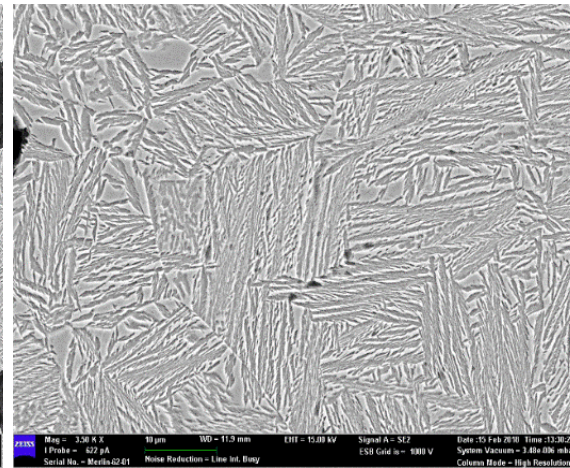
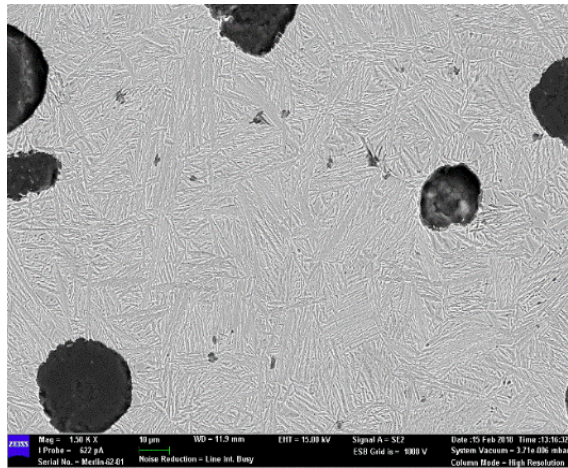
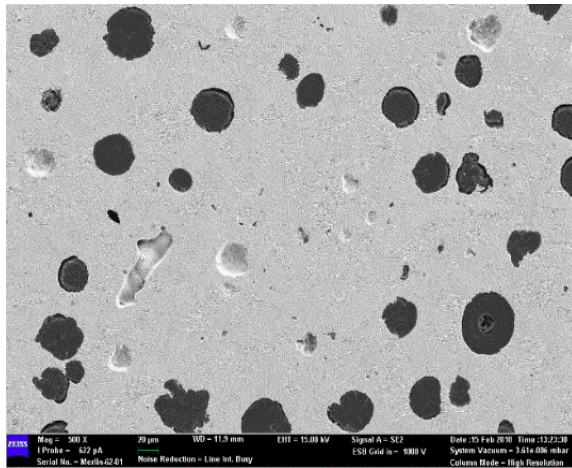
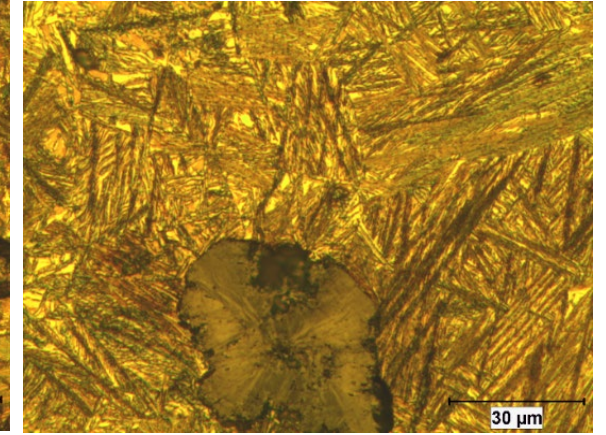
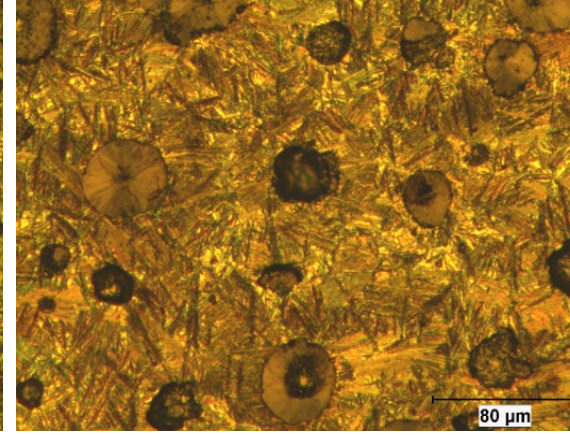
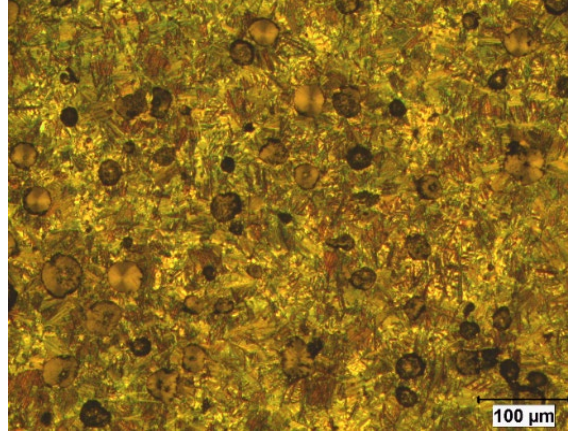
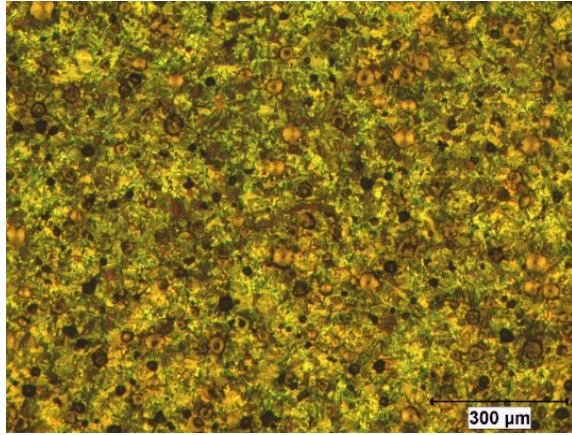


Ferrit Oranı: % 49,81

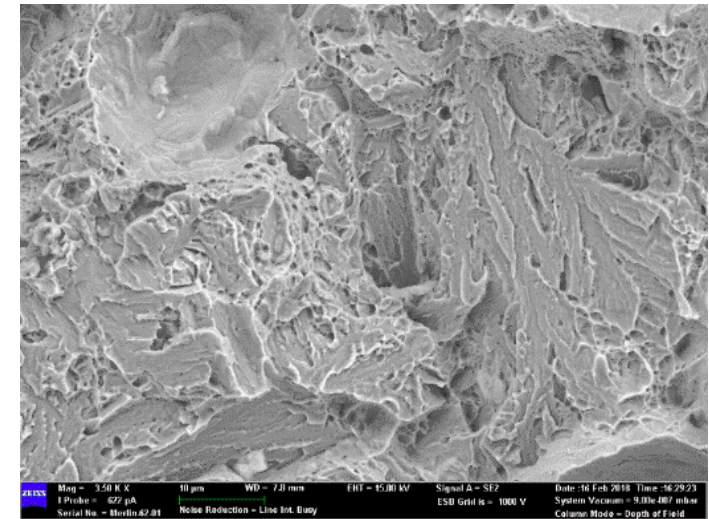
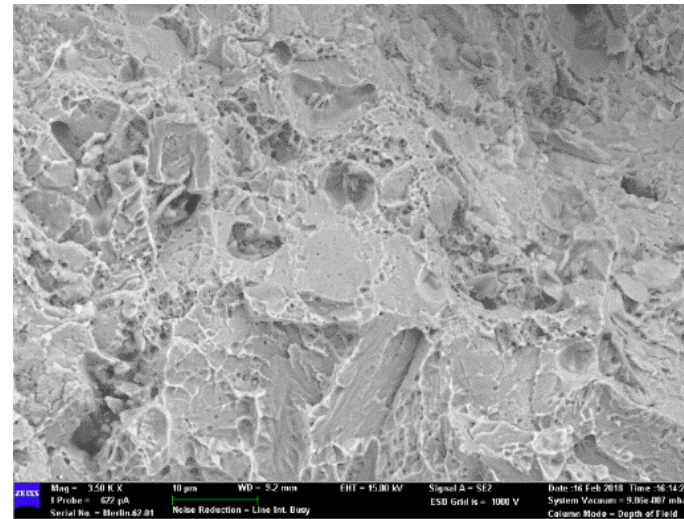
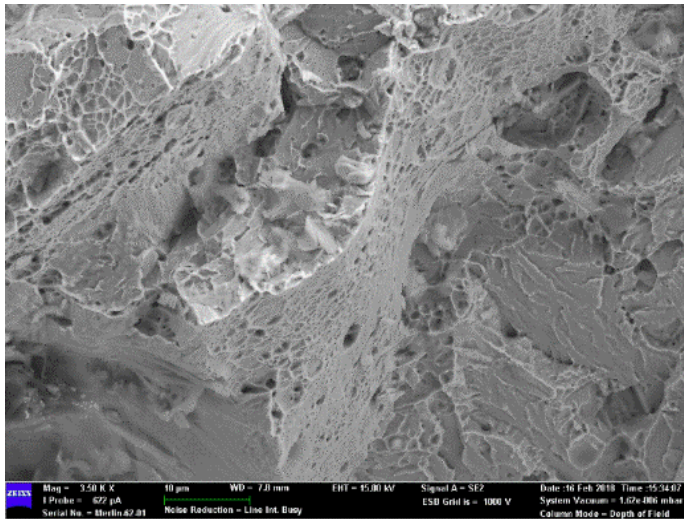
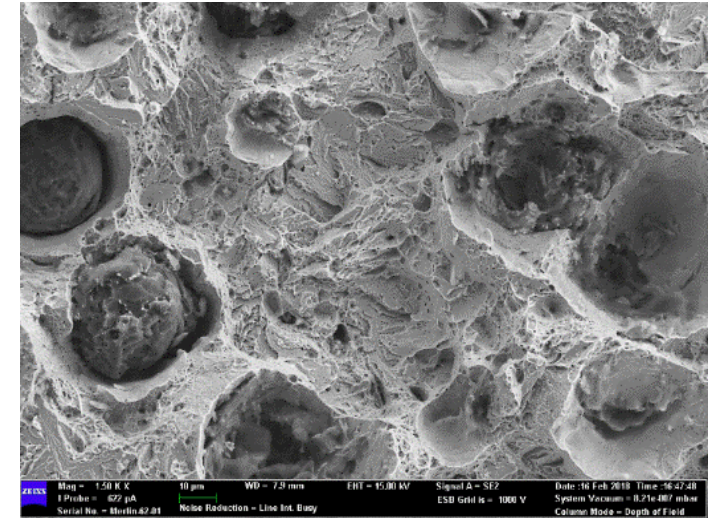
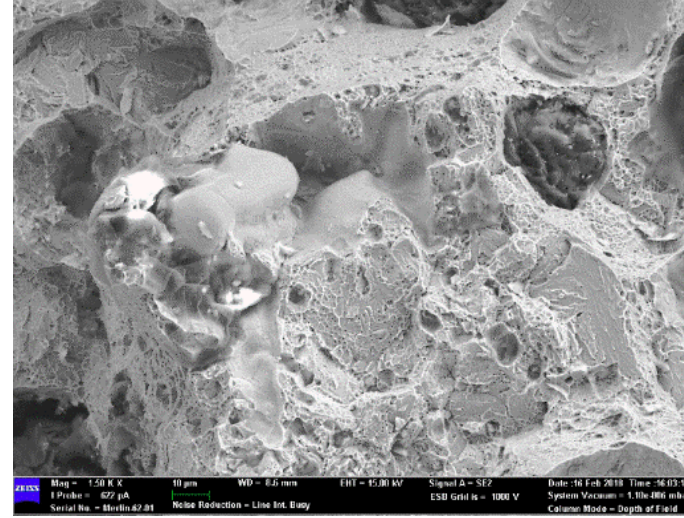
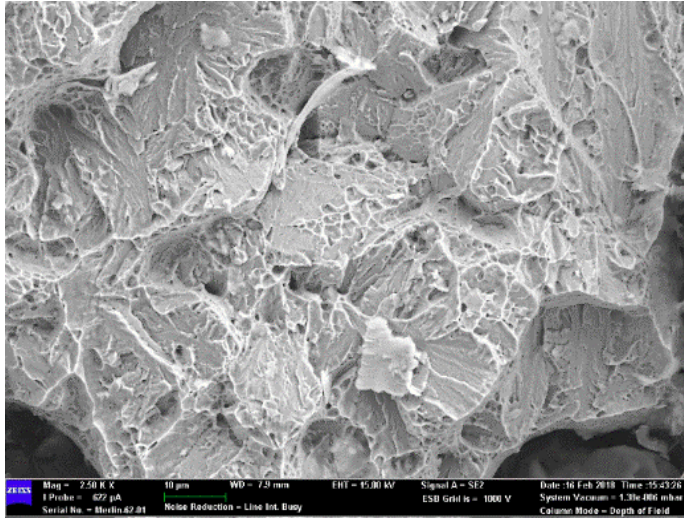


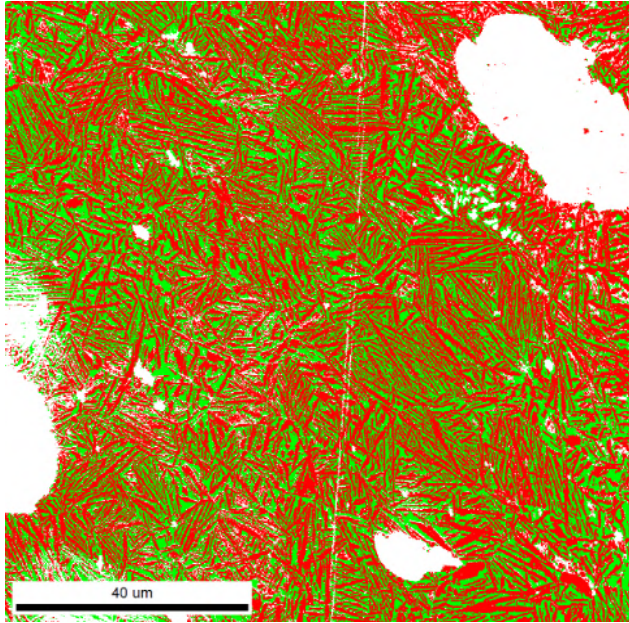
Ferrit Oranı: % 16,43

Niceliksel Metalografi Çalışmaları

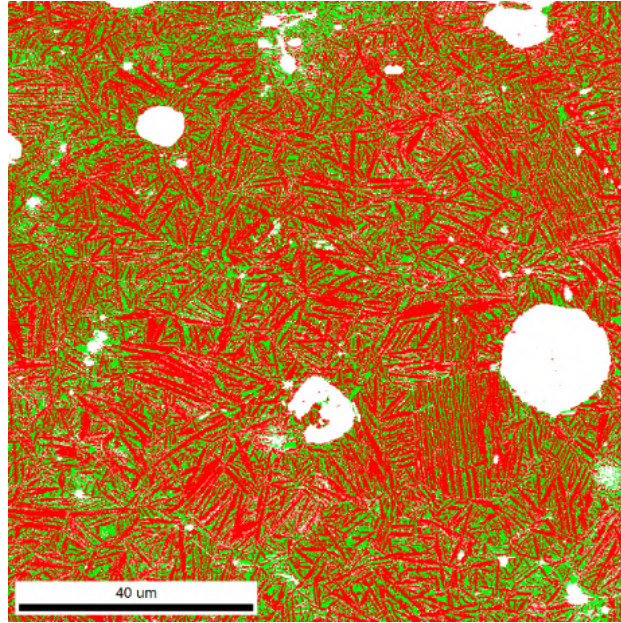


Niceliksel Metalografi Çalışmaları

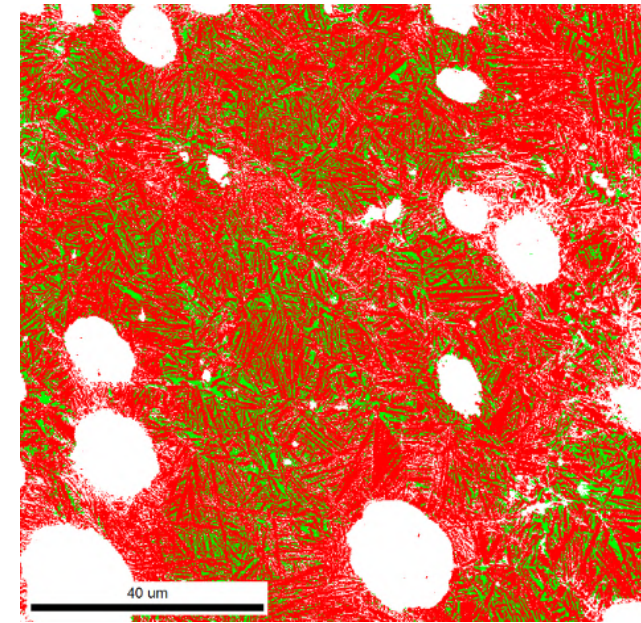




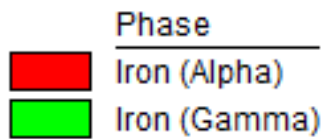
Ret- γ : 41.1%



Ret- γ : 32.5%



Ret- γ : 20.5%



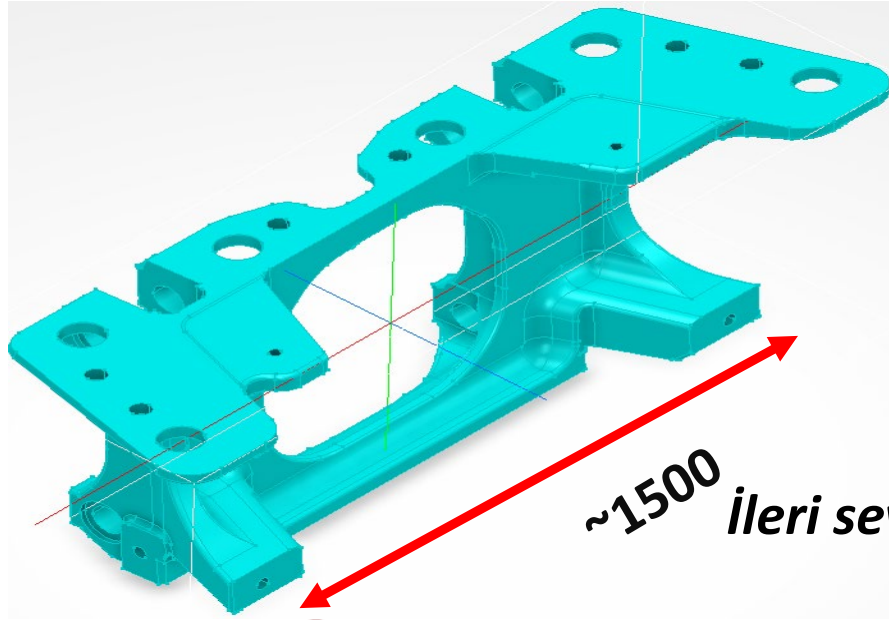
Alloying additions shift the TTT-curves to longer durations

Alloying additions slow down transformation kinetics (for ausferrite)

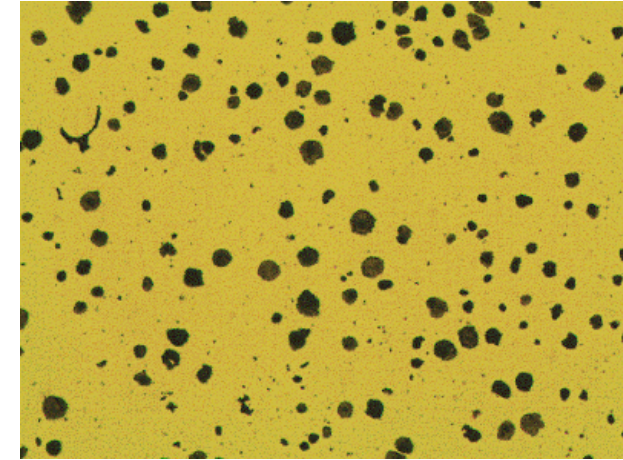
→ For the same austempering temperature & durations, higher alloy castings have lesser retained austenite



Niceliksel Metalografi Çalışmaları



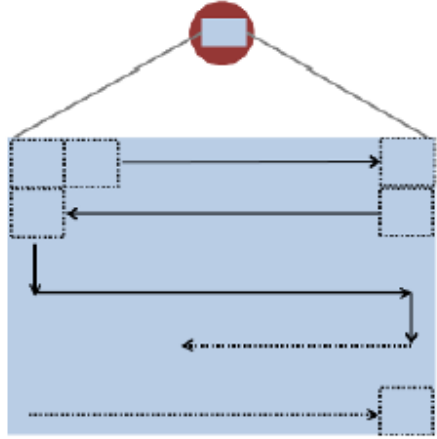
~600



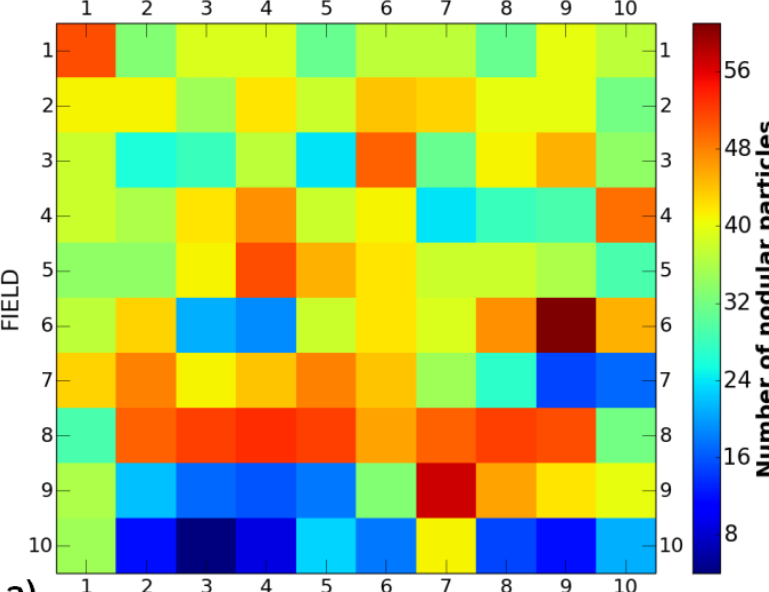
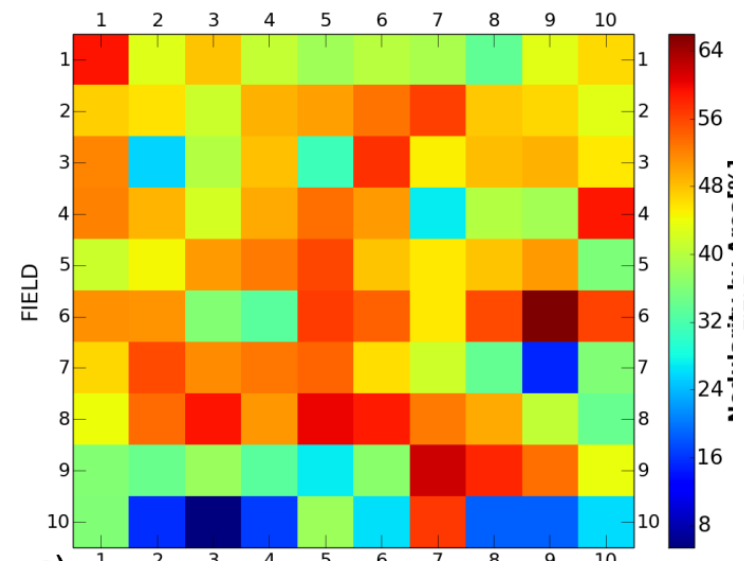
~ 1,2 mm²



ileri seviyeli nodularite hesabı gereklidir.



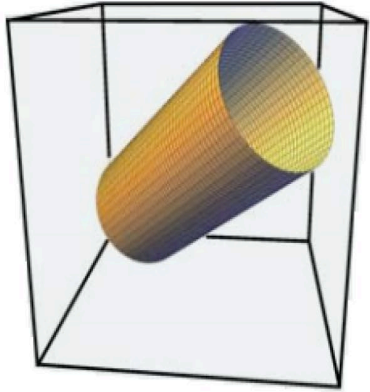
10X10 Scan = 100 Fields



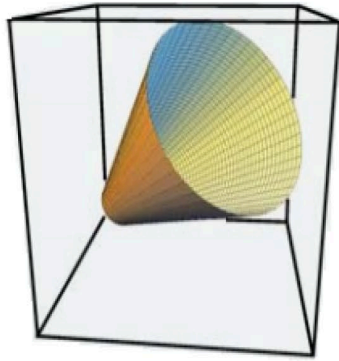


İleri Seviyeli Mekanik Karakterizasyon

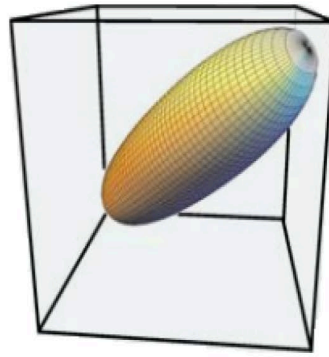
von Mises



Drucker-Prager



Gurson

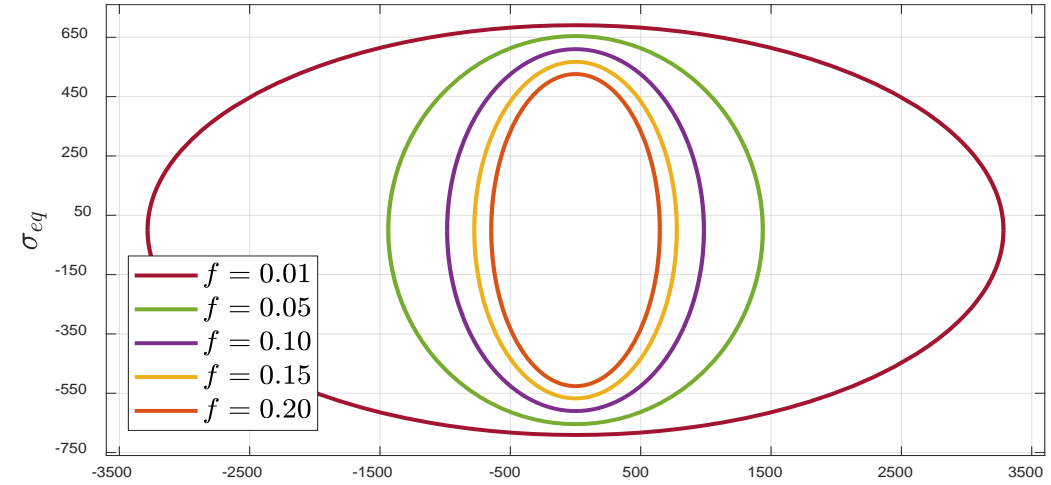


Yield surfaces

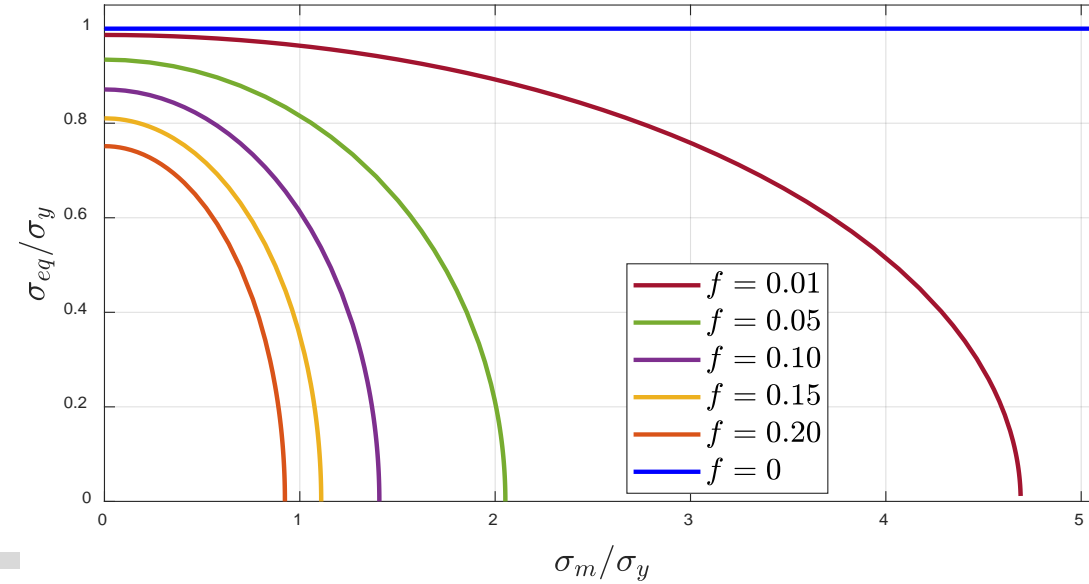
von Mises: $f = \|\sigma'\| - \sqrt{\frac{2}{3}}Y$

Drucker-Prager: $f = J_2^{\frac{1}{2}} + \frac{1}{3}I_1 - k$

Gurson: $f = (\frac{\bar{\sigma}}{Y})^2 + 2f^*q_1 \cosh(\frac{3}{2}\frac{q_2p}{Y}) - (1 - q_3f^{*2})$

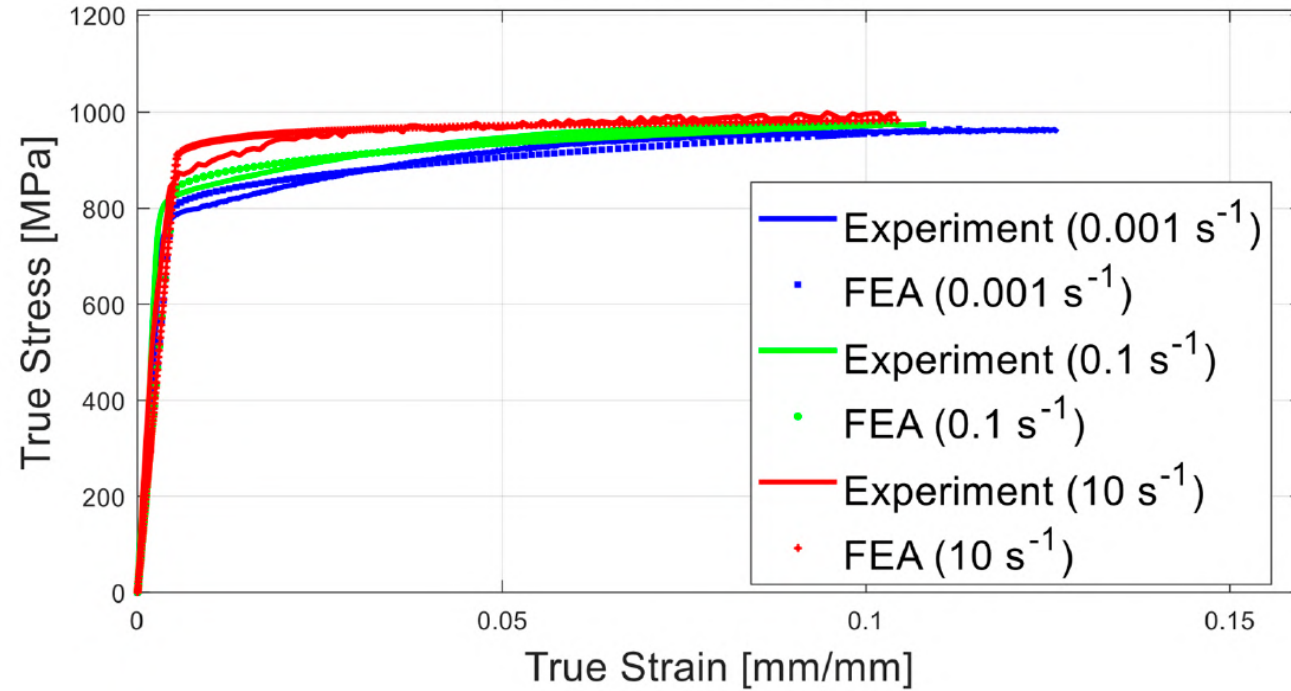


Normalized Yield Locus of Cocks'89

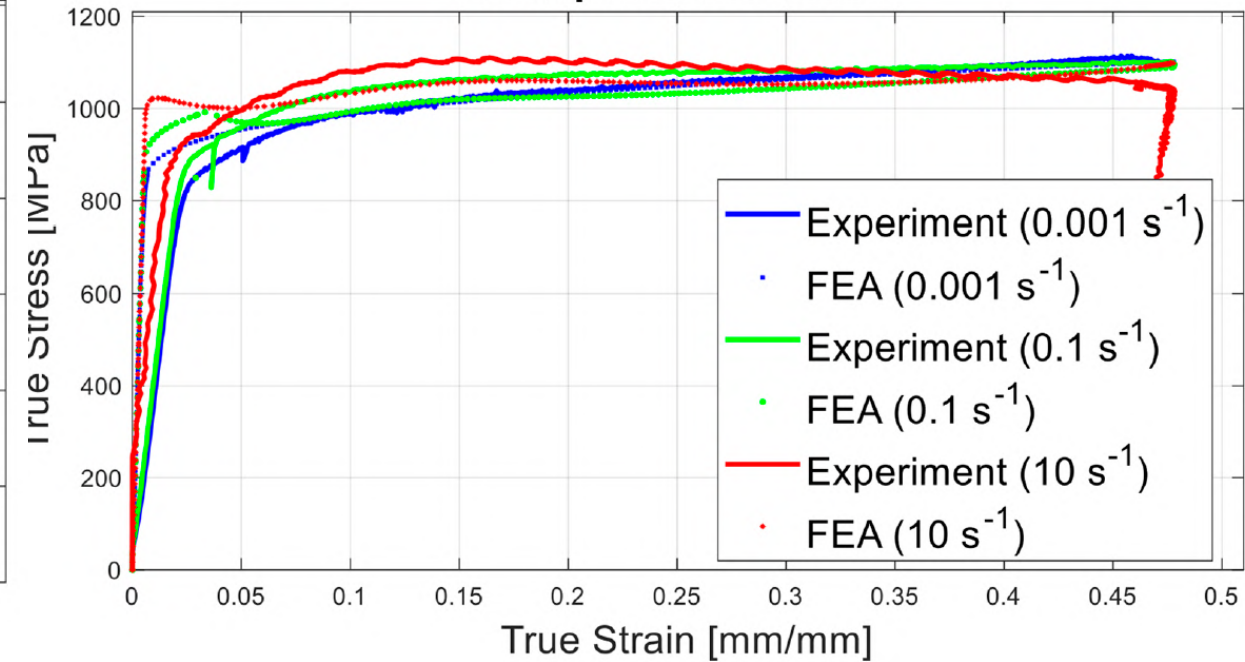




Tensile Tests



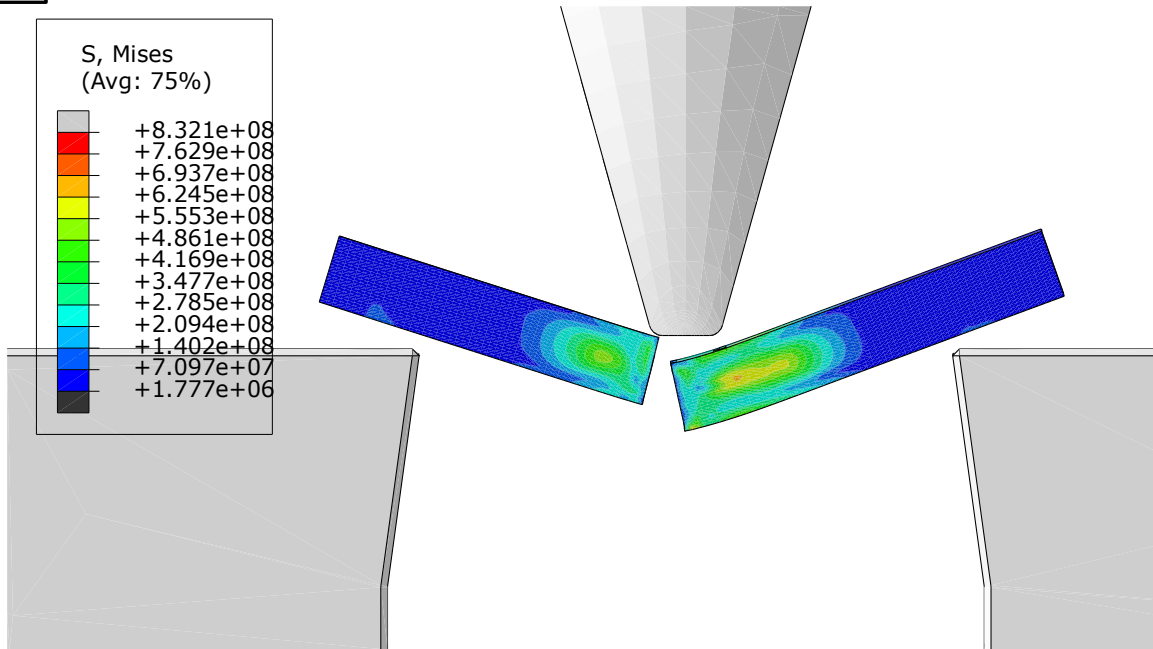
Compression Tests



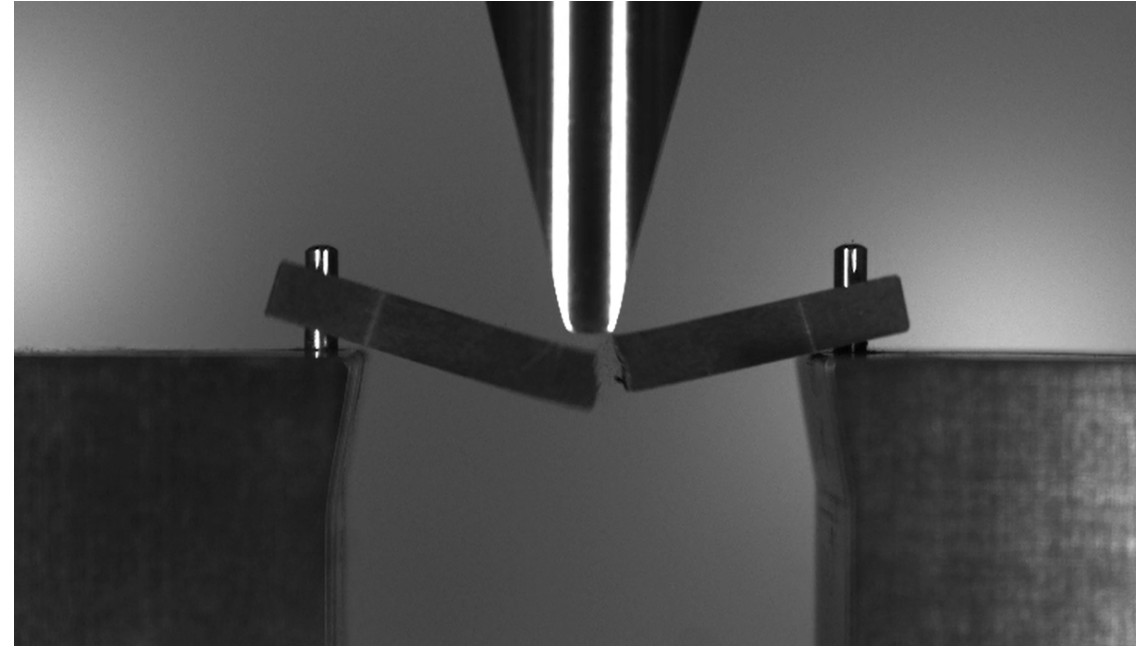
İleri Seviyeli Mekanik Karakterizasyon



a)



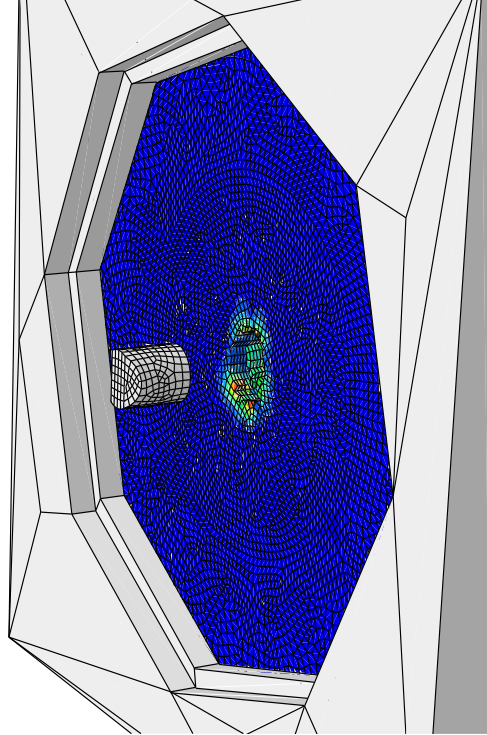
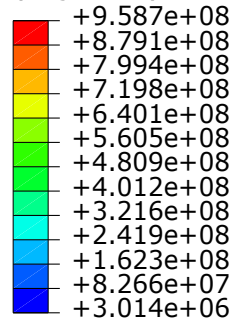
b)



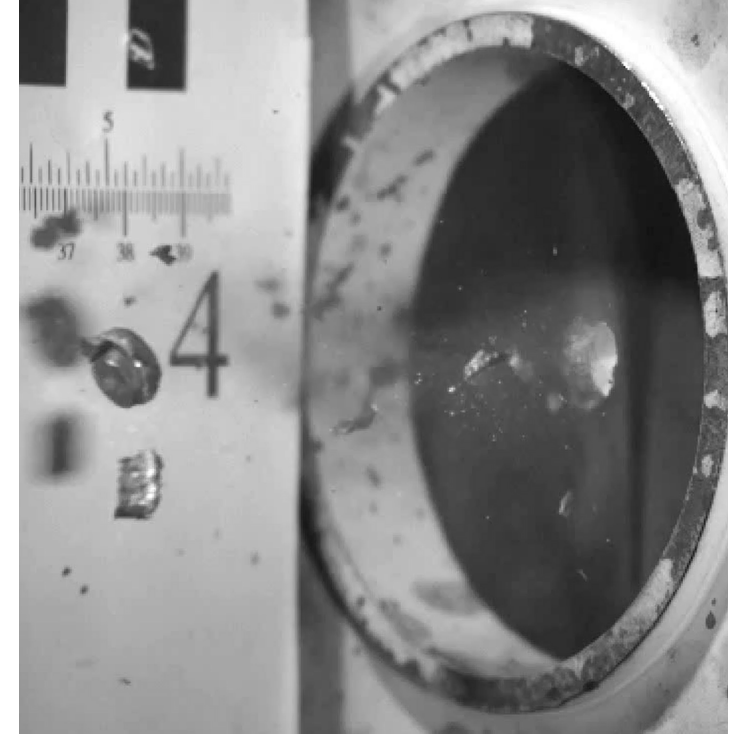


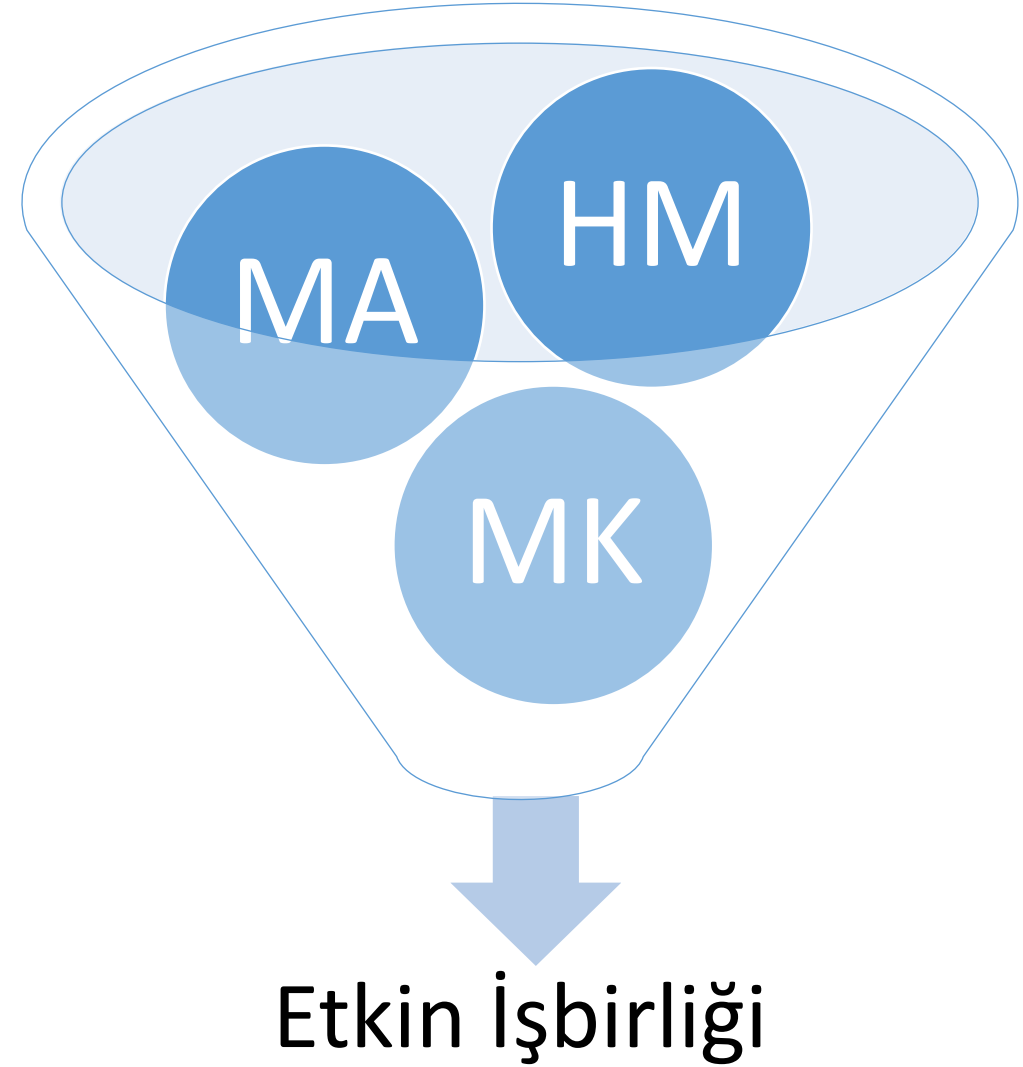
a)

S, Mises
(Avg: 75%)



b)





FNSS

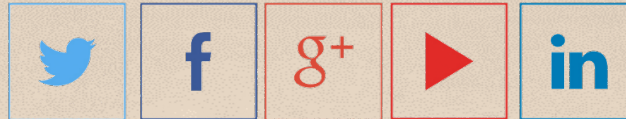
Soru & Cevap

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tüm paydařlarımıza
teřekkürlerimizi
sunuyoruz.**

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