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Investigation of the Effect on the Mechanical Properties of Gun Body Produced from Three Different Alloy Steel by Hot Forging Method at Three Different Temperatures

Ali Debre[1,2]
[1]Mechanical Engineering Department, Bursa Uludağ University, Bursa, 16059, Turkey
[2]MSK Steel Forging Ltd., Karacabey - Bursa, 16700, Turkey

Ali Bayram[1]
[1]Mechanical Engineering Department, Bursa Uludağ University, Bursa, 16059, Turkey

Abstract:- Forging production method is a preferred production method compared to other production methods in terms of high mechanical properties of the product. In the forging production method, production can be made using materials of different qualities. In addition, one of the areas of interest in the forging sector in recent years is the studies on the malleability of alloy steels. The use of alloy steels can show superior properties especially in terms of strength and machinability. In this study, gun bodies were produced from three different alloy steels (41Cr4, 42CrMo4 and AISI420) at different forging temperatures (800°C, 950°C and 1250°C). Hardness, microstructure, notch impact, tensile test and SEM examinations were carried out by taking samples from the gun body and their effects on mechanical properties were investigated. The data obtained as a result of the experiments were verified by microstructure and SEM examinations.

Keywords:- *Alloy Steel, Forging, Gun, Mechanical Properties, Hot Forming, Stainless Steel, Temperature.*

I. INTRODUCTION

Forging, one of the oldest known metalworking processes with origins dating back thousands of years, is a process in which the workpiece changes its plastic shape under the influence of compressive forces [1,2]. In history, the art of forging started to be applied with the transition from the stone age to the metal age and developed as a handicraft until the end of the 18th century. After this date, with the replacement of manpower by machines, the workshops where the art of forging was applied entered the path of industrialisation. In the late 19th century and especially in the 20th century, very rapid developments were experienced in the forging industry as in all technological developments [3].

Forging processes are carried out hot (above the recrystallisation temperature), semi-hot (just below the recrystallisation temperature) and cold (usually at or near room temperature). Due to the high strength of the material, cold forging requires very high forces and the workpiece must have sufficient flexibility at room conditions to perform this process. Cold forgings have good surface quality and dimensional accuracy. Hot forging requires smaller forces, but the surface quality and dimensional accuracy are not as good [4].

Forging is a preferred manufacturing process in terms of improving the properties of the final product. The properties of the final product are directly related to the material used in the forging process. Main parameters such as forging temperature, number of stages, pre-die design, billet dimensions can be affected by the forging material [5].

Parts produced by the hot forging industry are used in many industrial sectors due to their high strength properties [6]. Most of the hot forging dies are applied in the form of forging into closed dies.

Parts produced by the hot forging industry are used in many industrial sectors due to their high strength properties. Most of the hot forging dies are applied as forging into closed moulds. However, carbon and low alloy steels and aluminium alloys constitute the majority of the parts produced by forging method in the world. Stainless steels, nickel-based superalloys and titanium are also forged, especially for space applications. Most of the parts produced by forging are used in the automobile industry, about a quarter in trucks and tractors, and the rest in aircraft, railway, mining and other applications [6].

Alloys are one of the main interests of the forging industry. The use of alloy steels can provide superior properties, especially in terms of strength and machinability [5].

In this study, the effect of three different alloy steels on the mechanical properties of gun bodies produced by hot forging at three different temperatures was investigated.

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II. METHODOLOGY

➢ *Material Properties and Test Samples*

41Cr4, 42CrMo4, AISI420 steels were used in the experimental studies. The chemical compositions of these steels are given in Table 1. The gun body was selected as a prototype for the forging process (Figure 1). The forging process was carried out in three steps (crushing, pre-forming, final forming) at three different temperatures (800°C-950°C-1250°C) in a 1600 tons press.

Table 1 Chemical Composition of Raw Materials

Material	**C**	**Mn**	**P**	**S**	**Si**	**Cr**	**Mo**
41Cr4	0.38-0.45	0.6-0.9	Max. 0.025	Max. 0.035	Max. 0.4	0.9-1.2	0.15-0.3
42CrMo4	0.38-0.45	0.6-0.9	Max. 0.025	Max. 0.035	Max. 0.4	0.9-1.2	
AISI420	0.20	Max. 1.0	Max. 0.04	Max. 0.03	Max 0.01	13.0	

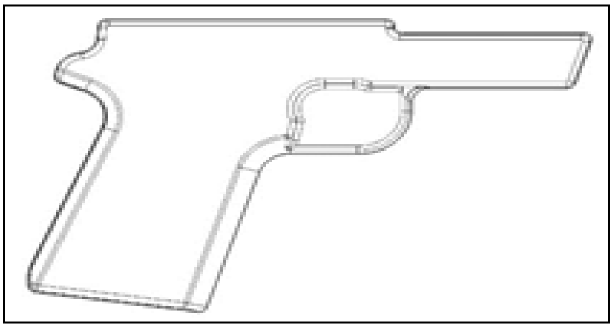

Fig 1 Gun Body Forging Model

The samples prepared for microstructure examination were cut with MetaCut 251 sample cutting device from the region where the A-A cross section was given. The cut 41Cr4 and 42CrMo4 samples were polished by metallographic methods and the samples were etched with etchant containing 100 ml ethanol + 5 ml HCl + 1 ml picric acid for about 15-20 seconds. AISI420 quality samples were polished by metallographic methods and etching process was carried out for 15-20 seconds using Fry reagent. The samples were analysed with Olympus-GX41 optical light microscope.

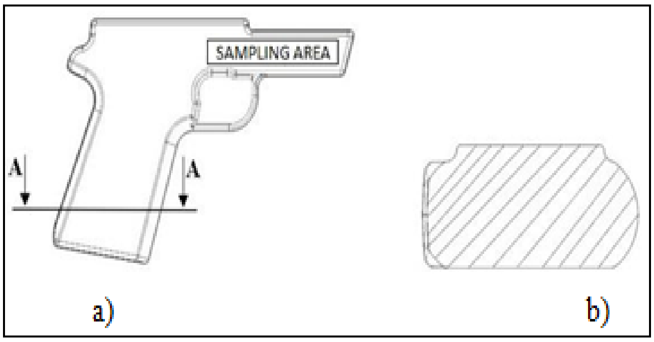

Fig 2 Sample Piece Sample Zones a) Samples Taken from the Barrel end b) A-A Cross-Section for Hardness Measurement

Hardness measurements were made in Brinell (approximately 10 s with 2.5 mm steel ball and 187.5 kg load) with BMS-3000 Bulut brand hardness tester. Tensile and notch impact test specimens were taken from the barrel area of the gun body and tested with Shimadzu AG-X Plus 250 kN universal tester and Alşa Laboatory Instruments Notch Impact Tester, respectively (Figure 2.a). ZEISS GeminiSEM 300 device was used for SEM examinations. SEM images were taken from the fracture surfaces of the notch impact test specimens.

III. RESULTS AND DISCUSSION

A. *Microstructure Investigations*

The microstructures of 41Cr4, 42CrMo4 and AISI420 steels forged at different temperatures are shown in Figure 3-11. The microstructure of 41Cr4 steel forged at 800°C consists of ferrite and pearlite phases. Light coloured areas indicate ferrite phase, dark coloured and lamellar areas indicate pearlite phase (Figure 3). In the ferrite and pearlite structure, it is not possible to transform the structure into 100% austenite phase as a result of heating up to 800 °C. However, it is seen that the internal structure of 41Cr4 steel forged at 950°C and 1250°C consists of ferrite and pearlite phases. The light coloured areas show the ferrite phase and the dark coloured and lamellar areas show the pearlite phase (Figure 4-5). Forging operations at 950°C and 1250°C were carried out in the austenite region and since the gun body was cooled in air, a very small amount of martensite phase was observed, but the pearlite and ferrite phase was largely preserved. When the internal structures formed as a result of heating up to 950°C and 1250°C are examined, it is noteworthy that there is a coarser grained structure compared to 800°C.

The internal structure of 42CrMo4 steel is shown in Figures 6-7-8. As a result of 800 °C forging process, ferrite and pearlite phases were formed (Figure 6). In general, a martensitic structure is formed as a result of forging at 950°C and martensite needles are large. There is also a small amount of ferrite and it is light coloured. The structure formed as a result of forging at 1250°C is martensite and martensite needles are thinner than martensite needles formed as a result of forging at 950°C. The most important difference between the compositions of 41Cr4, 42CrMo4 steels is that 42CrMo4 steel contains some Mo. Since Mo element reduces the critical cooling rate of 42CrMo4 steel, martensite phase is observed at 950°C and 1250°C in the microstructure as a result of forging and subsequent air cooling.

The structures formed as a result of forging AISI 420 steel at 800 °C, 950 °C and 1250 °C are shown in Figures 9-11. The structure formed as a result of forging the steel at 800 °C, 950 °C generally consists of ferrite and Fe_3C phase precipitated at the grain boundaries. However, grey chromium carbide phases precipitated in the grain can also be seen (Figure 9-10). It is seen that the microstructure at 1250°C consists of martensite phase. In addition, chromium carbide phases are observed between martensite needles. As a

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result of heating up to 1250°C, it is possible for the steel with ferrite and pearlitic structure to completely transform into austenite phase as a result of cooling in air and to transform into martensite due to its high chromium content - chromium reduces critical cooling.


Fig 3 800°C-41Cr4-500x Microstructure Image


Fig 4 950°C-41Cr4-500x Microstructure Image

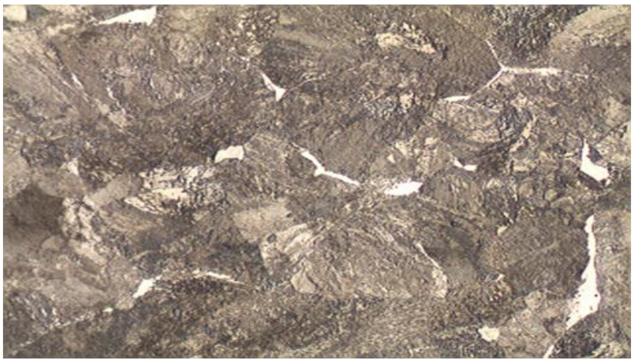
Fig 5 1250°C-41Cr4-500x Microstructure Image

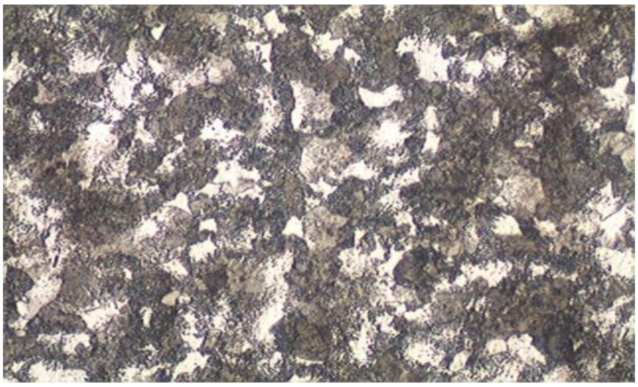
Fig 6 800°C-42CrMo4-500x Microstructure Image

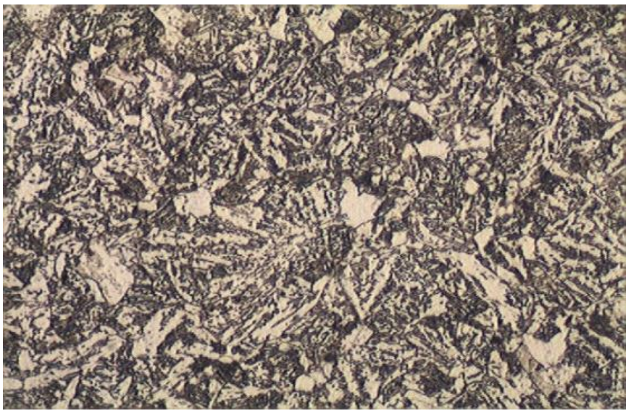
Fig 7 950°C-42CrMo4-500x Microstructure Image

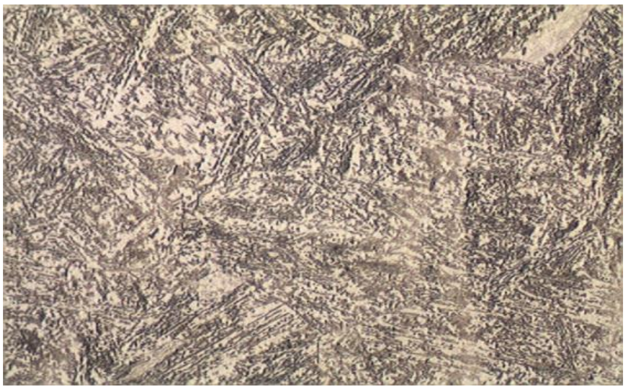
Fig 8 1250°C-42CrMo4-500x Microstructure Image

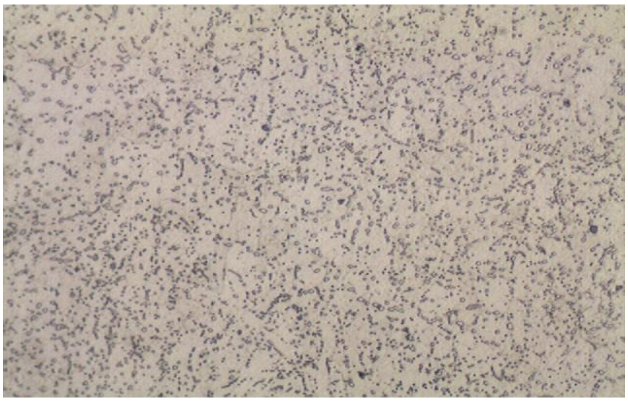
Fig 9 800°C-AISI420-500x Microstructure Image

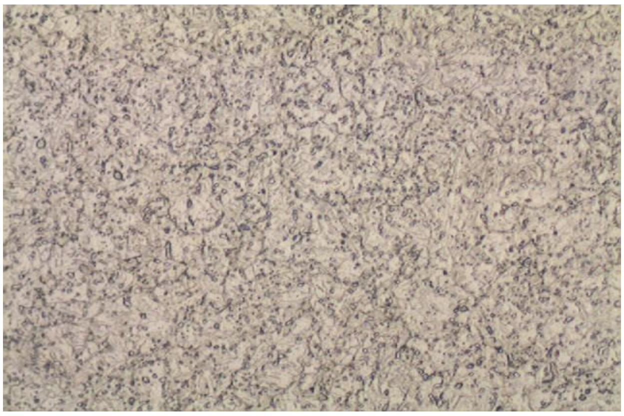
Fig 10 950°C-AISI420-500x Microstructure Image

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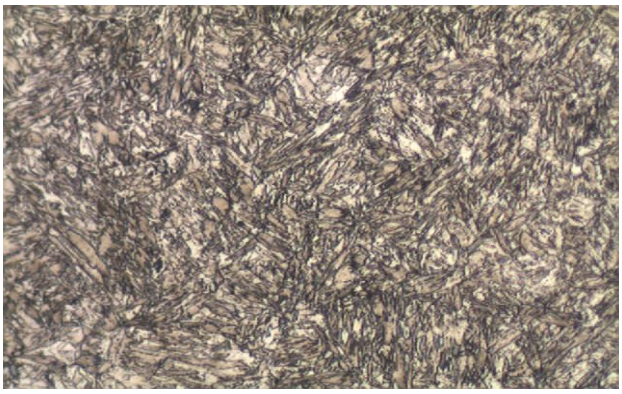
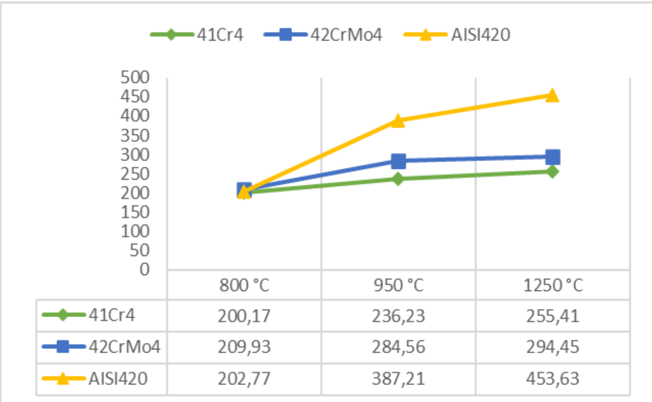


Fig 11 1250°C-AISI420-500x Microstructure Image

B. *Hardness Investigations*

Hardness measurements of 41Cr4, 42CrMo4 and AISI 420 steels forged at different temperatures were made from five different regions and averages were taken. The change in hardness values is shown in Figure 12.



	800 °C	950 °C	1250 °C
41Cr4	200,17	236,23	255,41
42CrMo4	209,93	284,56	294,45
AISI420	202,77	387,21	453,63

Fig 12 Hardness Measurement Values

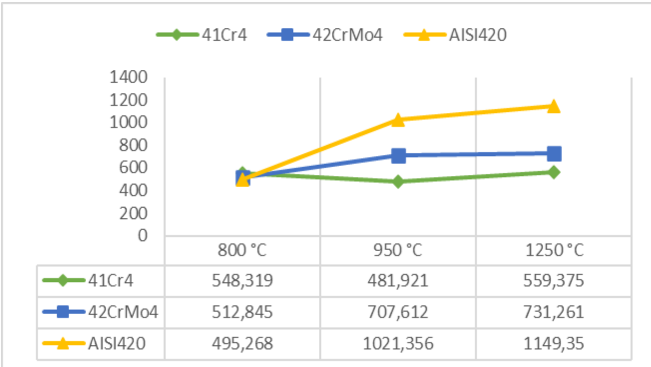
It is seen that the hardness values of the steels forged at 800°C are very close to each other. Since the carbon ratios of 41Cr4, 42CrMo4 steels are 0.40% C and their microstructures consist of ferrite + pearlite phase, it is natural that the hardness values are close to each other. Since AISI 420 steel has carbide particles dispersed in the ferrite matrix, it can be expected to be close to the hardness values of the other two steels (Figure 9).

When the hardness values of the steels forged at 950°C were analysed, the lowest hardness was obtained in 41Cr4 steel and the highest hardness was obtained in AISI 420 steel. Hardness differences are related to the internal structures formed as a result of forging. In the microstructure of 41Cr4 steel, the pearlite and ferrite phase is largely preserved, but a very small amount of martensite phase is observed. Therefore, the hardness value is lower than 42CrMo4 and AISI 420 steels.42CrMo4 microstructure is generally in the form of coarse martensite needles and a small amount of ferrite.42CrMo4 steel has higher hardness values than 41Cr4 steel due to the coarse needle martensite phase in its structure. The highest hardness value in AISI 420 steel is due to the grain boundaries of the ferrite phase and the Fe_3C and chromium carbide phases precipitated in the grain (Figure 10).

When the hardness values of the steels forged at 1250°C were analysed, the lowest hardness was observed in 41Cr4 steel and the highest hardness was observed in AISI 420 steel. When the internal structures formed at 1250°C are examined (Figure 5), 41Cr4 is in the form of coarse-grained pearlite phase and elongated ferrite around the grains of the pearlite phase. On the other hand, the microstructure of AISI 420 steel forged at 1250°C consists of martensite phase with fine needles. The reason why the hardness value of AISI 420 steel is higher than 42CrMo4 steel is that the martensite needles formed in AISI 420 steel are thinner than those formed in 42CrMo4 steel. The hardness difference is related to the structure of martensite needles.

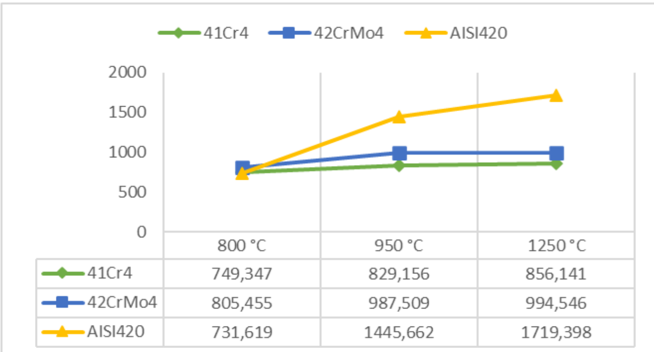
C. *Tensile Test Investigations*

Four tensile specimens were prepared from each of 41Cr4, 42CrMo4 and AISI 420 steels forged at different temperatures and the test results obtained were averaged.



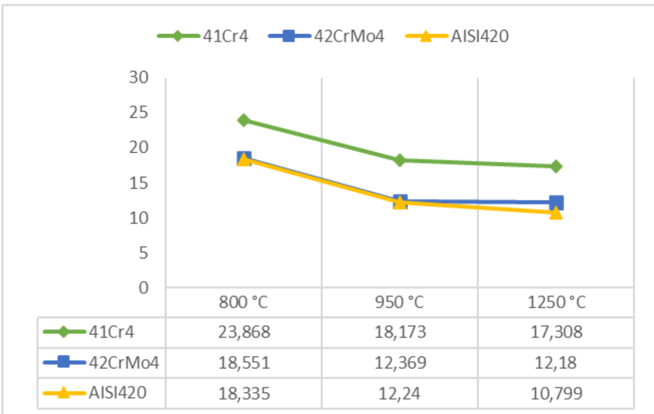
	800 °C	950 °C	1250 °C
41Cr4	548,319	481,921	559,375
42CrMo4	512,845	707,612	731,261
AISI420	495,268	1021,356	1149,35

Fig 13 Yield Strength Values



	800 °C	950 °C	1250 °C
41Cr4	749,347	829,156	856,141
42CrMo4	805,455	987,509	994,546
AISI420	731,619	1445,662	1719,398

Fig 14 Tensile Strength Values



	800 °C	950 °C	1250 °C
41Cr4	23,868	18,173	17,308
42CrMo4	18,551	12,369	12,18
AISI420	18,335	12,24	10,799

Fig 15 Elongation Values

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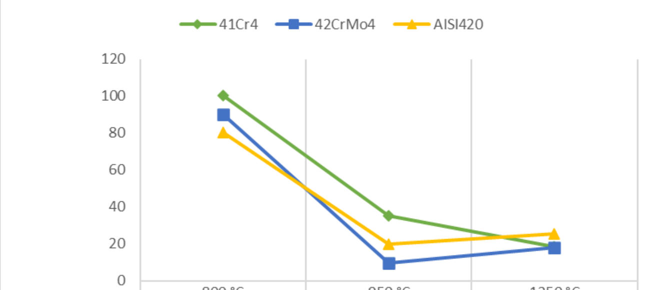
The yield and tensile strengths and % elongation of these steels at 800 °C are compatible with their internal structures formed as a result of forging. While the lowest yield strength was obtained in AISI 420 steel, the highest yield strength was observed in 41Cr4 steel. The lowest tensile strength was observed in AISI 420 steel, while the highest value was observed in 42CrMo4 steel. The lowest % elongation was observed in AISI 420 steel. When the microstructure of AISI 420 steel is examined, carbide precipitates are observed in the ferrite matrix. Since these carbides prevent dislocation movements during the force applied to the material, the % elongation value was lower than other steels. Therefore, the lowest % elongation is expected to be obtained in AISI 420 steel.

In steels forged at 950°C, the lowest yield and tensile strengths were obtained in 41Cr4 steel, while the highest values were found in AISI 420 steel. It was observed that strength values and % elongation values were inversely proportional (Figure 15). The lowest % elongation value was obtained in AISI 420 steel. However, the % elongation values of AISI 420 and 42CrMo4 steels are very close to each other. The microstructure of 42CrMo4 steel is generally martensitic and martensite needles are large. However, there is also a small amount of ferrite in the structure. In AISI 420 steel, on the other hand, it generally consists of Fe_3C phase precipitated at ferrite and ferrite grain boundaries and a small amount of chromium carbide phases. Due to the internal structures of 42CrMo4 and AISI 420 steels, the % elongation values were lower than 41Cr4 steel. The high strength values of AISI 420 and 42CrMo4 are related to their internal structures. Because the microstructure of 41Cr4 steel consists of ferrite and pearlite phase. The strength was low due to ferrite and pearlite phases.

As expected, the lowest yield and tensile strength values were observed in 41Cr4 steel, while the highest tensile strength values were obtained in AISI 420 steel when these steels were forged at 1250 °C. On the other hand, the highest % elongation values were obtained in 41Cr4 steel. As at 800 °C and 950 °C forging temperatures, the mechanical properties of the steels were determined by their internal structure. The difference in the strength values of 42CrMo4 and AISI 420 steels is determined by the shape of martensite needles. Since the martensite needles of AISI 420 steel are thinner than 42CrMo4, higher values were obtained. Since 41Cr4 microstructure consists of ferrite and pearlite phase, it showed lower strength values. Since the hardness of 42CrMo4 and AISI 420 steels were higher than 41Cr4, they showed lower elongation values.

D. Notch Impact Test Investigations

Four notch impact test specimens were prepared from each of 41Cr4, 42CrMo4 and AISI 420 steels forged at different temperatures and the test results obtained were averaged.



	800 °C	950 °C	1250 °C
41Cr4	100,331	35,251	18,643
42CrMo4	90,162	9,489	17,965
AISI420	80,152	19,998	25,442

Fig 16 Notch Impact Test Values

When the notch impact test results of 41Cr4, 42CrMo4 and AISI 420 steels forged at 800°C were analysed, the highest fracture energy (impact energy) was obtained in 41Cr4 steel. The lowest fracture energy was observed in AISI 420 steel. When SEM images were examined (Figure 17, Figure 21, Figure 25), all three steels exhibited ductile fracture behaviour. When the fracture energy values are compared, there is approximately 20% difference between the lowest energy and the highest energy. When the hardness values of the steels forged at 800°C are examined, it is seen that they are close to each other (Figure 12). Hardness values also support the fracture energy change given.

When the notch impact test results of 41Cr4, 42CrMo4 and AISI 420 steels selected in the experimental studies were examined as a result of forging at 950 °C, the lowest fracture energy value was obtained in 42CrMo4 steel, while the highest value was observed in 41Cr4 steel. From the SEM images, 42CrMo4 exhibited a brittle fracture behaviour (Figure 22). Therefore, 42CrMo4 has the lowest fracture energy. 41Cr4 steel has the highest fracture energy because it exhibits ductile fracture behaviour (Figure 18). Mixed fracture behaviour is observed in AISI 420 steel (Figure 26). While a small amount of brittle zones are observed, a significant amount of grain displacement is observed. The fracture energy value obtained in AISI 420 steel is consistent with the fracture behaviour.

When the fracture energy values obtained as a result of forging at 1250°C are examined, the lowest value is obtained in 42CrMo4 steel, while the highest value is observed in AISI 420 steel. However, it is seen that the fracture energy values of 41Cr4, 42CrMo4 steels are very close. When SEM images are analysed, it is seen that they fracture in brittle style (Figure 19, Figure 23). In AISI 420 steel, mixed fracture is observed due to thin martensite needles. Both brittle and ductile regions are observed. It is seen that some grains are dislocated. Due to this structure, the highest fracture energy was observed in AISI 420 steel.

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E. SEM Investigations

➢ *SEM Investigations of 41Cr4 Steel*

SEM images obtained from the fracture surfaces of notch impact test specimens obtained from 41Cr4 steel forged at different temperatures are shown in Figures 17-19.

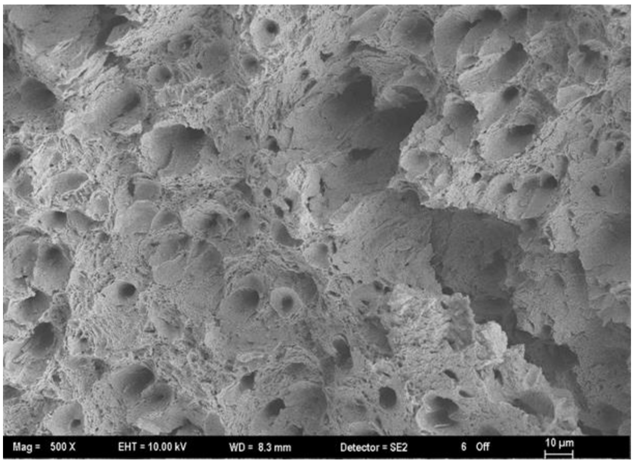

Fig 17 SEM Image at 800°C

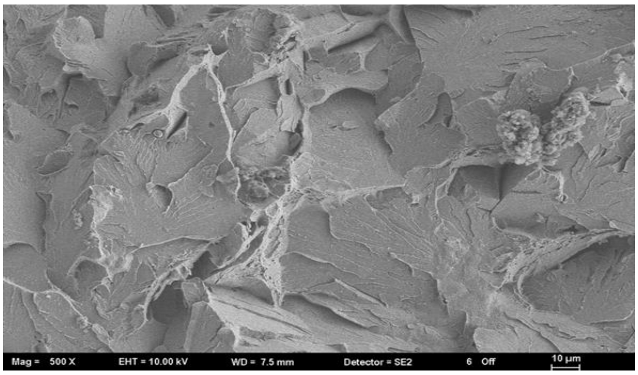

Fig 18 SEM Image at 950°C

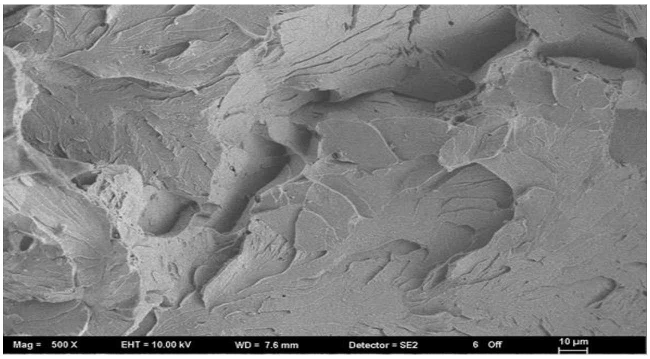

Fig 19 SEM Image at 1250°C

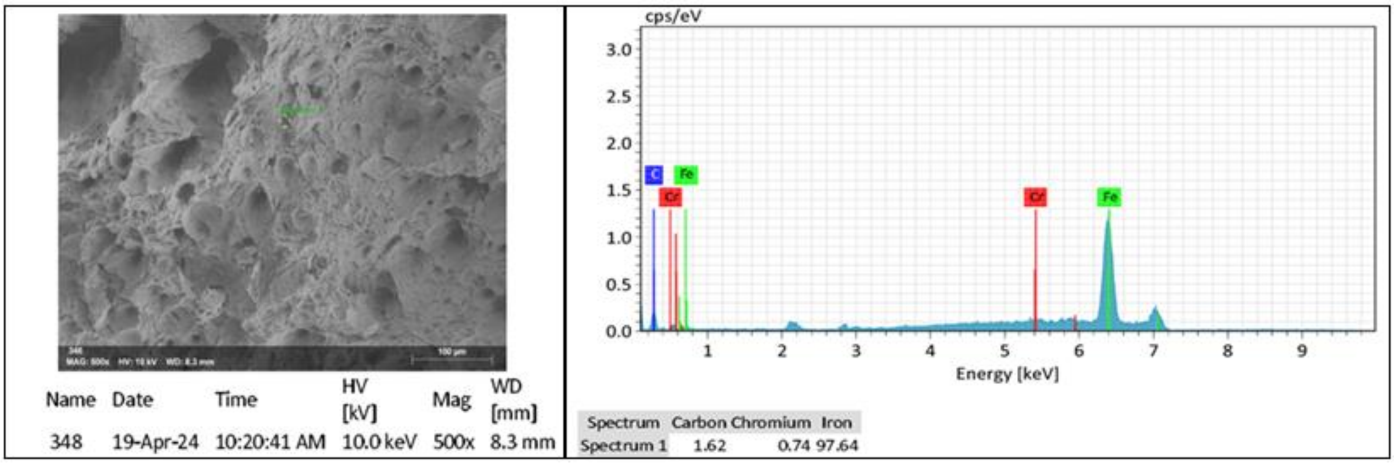

Fig 20 41Cr4 EDS Elemental Analysis Image at 800°C

When the structure formed at 800 °C as a result of the forging temperature is examined (Figure 17), it is seen that hollowing is formed. It is seen that there is a ductile fracture with the combination of pit formations. On the other hand, when the fracture surfaces at 950 °C and 1250 °C are examined, it is seen that there is a brittle fracture. In other words, an inter-plane fracture has occurred. It is seen that river lines are formed on the planes. With the merger of the river lines, a crack was formed and fracture occurred. The reason why steels forged at 950 °C and 1250 °C show a different fracture style than the material forged at 800 °C is the coarsening of the grains as a result of forging at high temperatures (Figure 3-5). It is known that the material becomes brittle as a result of grain coarsening [7]. The precipitate phases seen inside the voids in Figure 20 are chromium carbides.

➢ *SEM Investigations of 42CrMo4 Steel*

SEM images of the fracture surfaces of notch impact test specimens obtained from 42CrMo4 steel forged at different temperatures are shown in Figures 21-23.

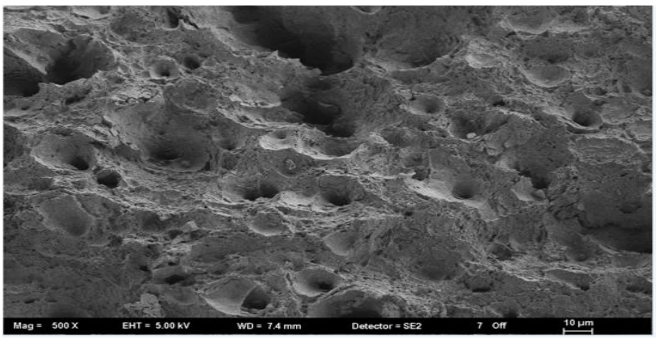

Fig 21 SEM Image at 800°C

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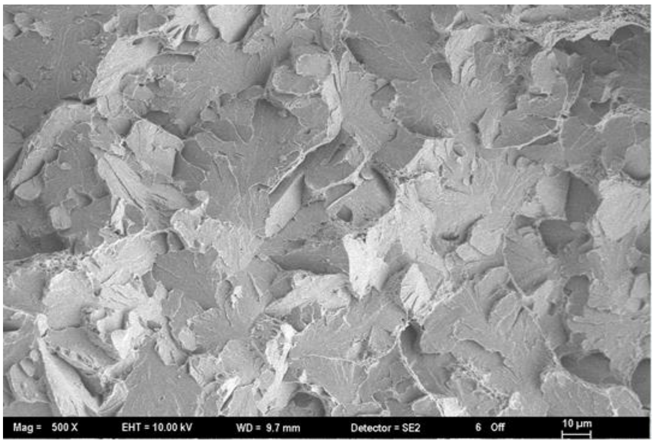

Fig 22 SEM Image at 950°C

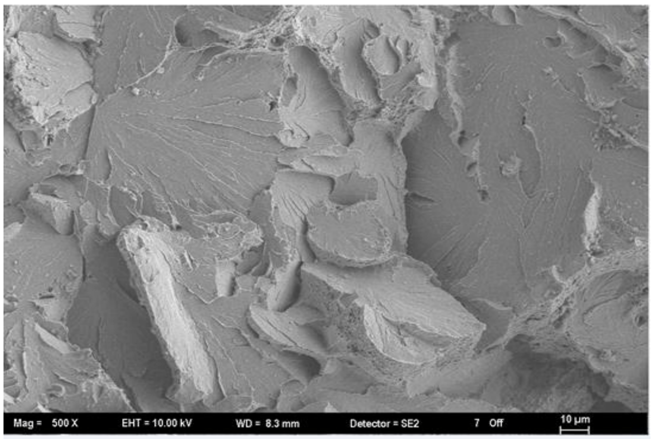

Fig 23 SEM Image at 1250°C

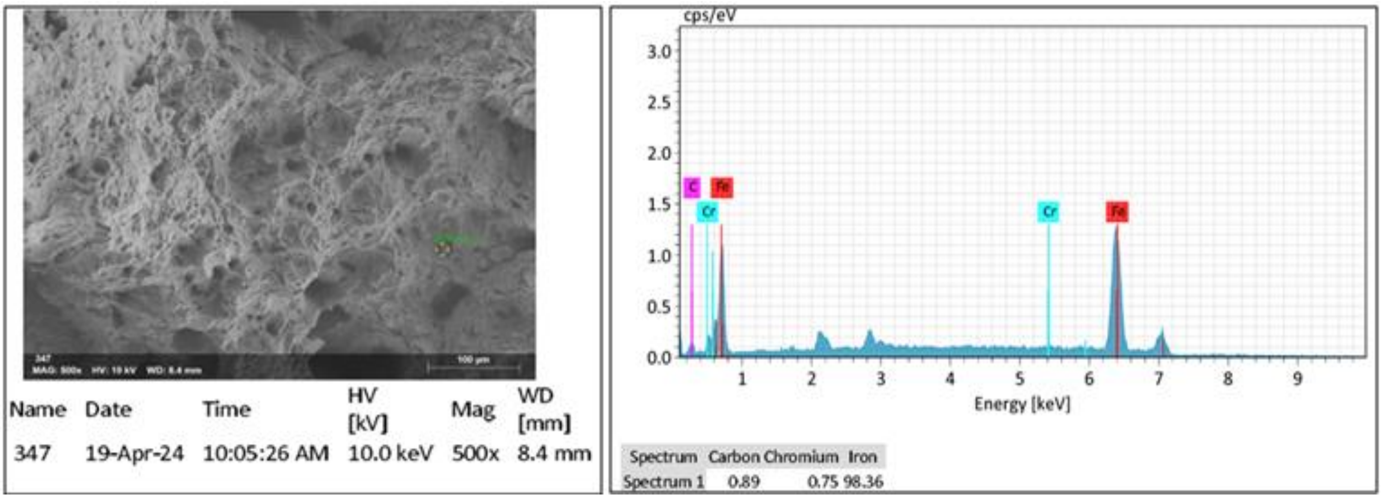

Fig 24 42CrMo4 EDS Elemental Analysis Image at 800°C

When the structure formed at 800 °C as a result of the forging temperature is examined (Figure 21), it is seen that hollowing is formed. It is seen that there is a ductile fracture with the combination of pit formations. On the other hand, when the fracture surfaces at 950 °C and 1250 °C are examined, it is seen that there is a brittle fracture. In other words, an inter-plane fracture has occurred. It is seen that river lines are formed on the planes. With the merger of the river lines, a crack was formed and fracture occurred. The reason why steels forged at 950°C and 1250°C show a different fracture style than the material forged at 800°C is due to the formation of a martensitic structure as a result of forging and cooling at high temperatures. (Figure 7-8) Martensite is a very hard and brittle phase and is an expected fracture behaviour. The precipitate phases seen in the voids in Figure 24 are chromium carbides.

- *SEM Investigations of AISI420 Steel*

SEM images of the fracture surfaces of notch impact test specimens obtained from AISI420 steel forged at different temperatures are shown in Figures 25-27.

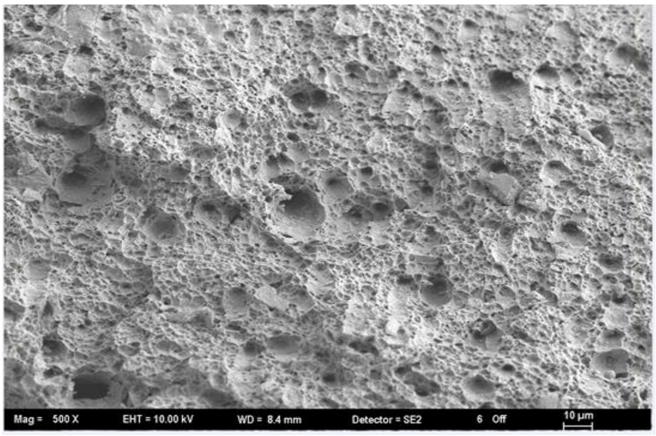

Fig 25 SEM Image at 800°C

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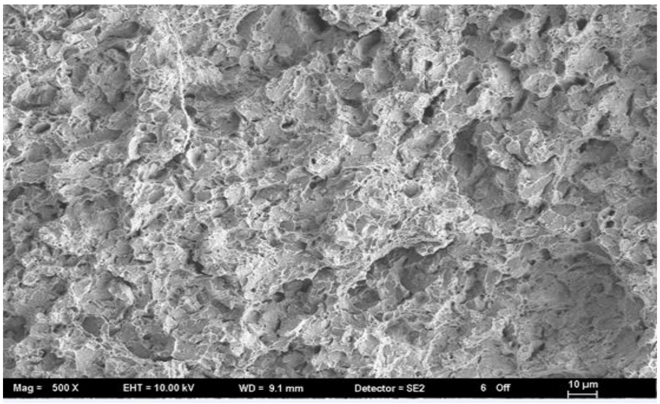


Fig 26 SEM Image at 950°C

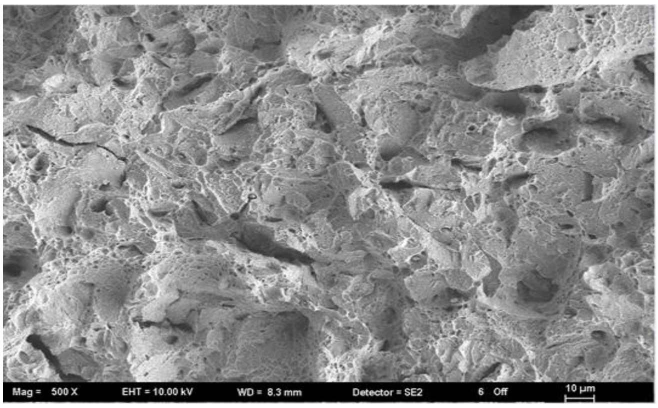
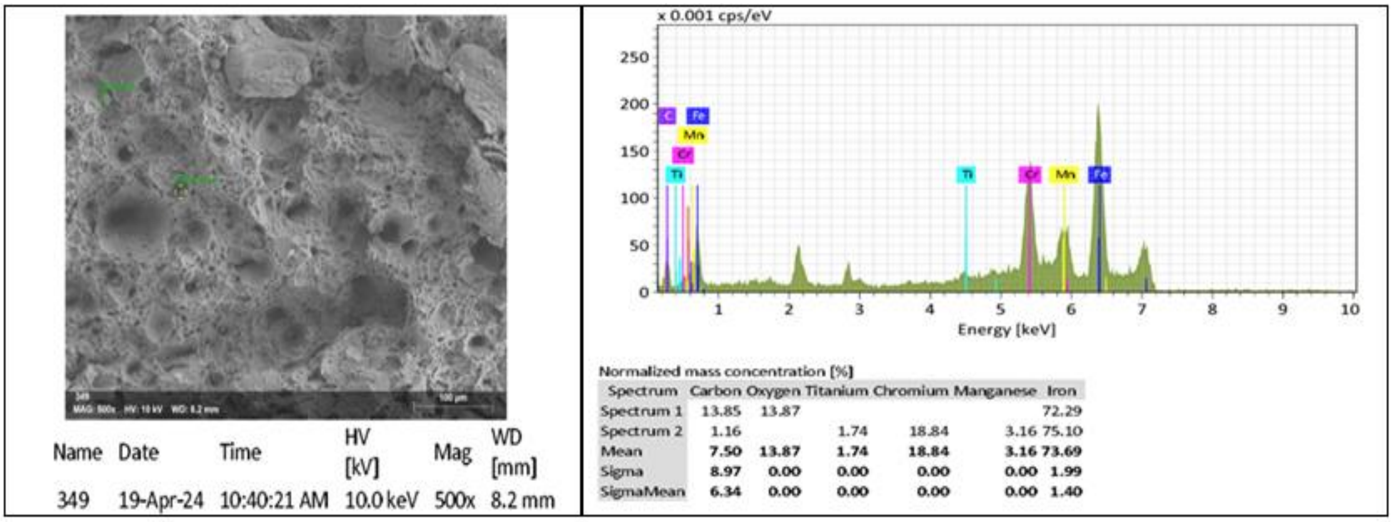


Fig 27 SEM Image at 1250°C



Name	Date	Time	HV [kV]	Mag	WD [mm]
349	19-Apr-24	10:40:21 AM	10.0 keV	500x	8.2 mm

Normalized mass concentration [%]

Spectrum	Carbon	Oxygen	Titanium	Chromium	Manganese	Iron
Spectrum 1	13.85	13.87				72.29
Spectrum 2	1.16		1.74	18.84	3.16	75.10
Mean	7.50	13.87	1.74	18.84	3.16	73.69
Sigma	8.97	0.00	0.00	0.00	0.00	1.99
SigmaMean	6.34	0.00	0.00	0.00	0.00	1.40

Fig 28 EDS Elemental Analysis Image of AISI420 at 800°C

When the structure formed at 800 °C as a result of the forging temperature is examined (Figure 25), it is seen that hollowing is formed. It is seen that there is a ductile fracture with the combination of pit formations. Very few brittle fracture zones are observed. At 950 °C, when the structure formed as a result of forging temperature is examined, it is seen that mixed fractures occur. While a small amount of brittle zones are observed, a significant amount of grain displacement is observed. The reason for this is the carbides precipitated at the grain boundaries (Figure 10). Precipitated carbides weakened the bonds between the grains. Steels forged at 1250°C were forged at high temperatures and a martensitic structure was formed as a result of cooling. Mixed fracture was observed due to fine martensite needles. Both brittle and ductile regions were observed. It is observed that some grains are dislocated. Secondary cracks are also observed. This is also related to the martensite phase. The precipitate phases seen inside the voids in Figure 28 are chromium carbides.

IV. CONCLUSION

As a result of the studies, the following results were obtained:

Hardness values of steels forged at 800 °C are very close to each other. When the hardness values of the steels forged at 950°C are examined, the lowest hardness is 41Cr4 and the highest hardness is obtained in AISI 420 steel. When the hardness values of the steels forged at 1250°C were examined, the lowest hardness was obtained in 41Cr4 and the highest hardness was obtained in AISI 420 steel.

At 800 °C, the lowest yield strength was obtained in AISI 420 steel, while the highest yield strength was observed in 41Cr4 steel. The lowest tensile strength was observed in AISI 420 steel and the highest value was observed in 42CrMo4 steel. The lowest % elongation was observed in AISI 420 steel. In steels forged at 950°C, the lowest yield and tensile strength values were obtained in 41Cr4 steel, while the highest values were found in AISI 420 steel. % elongation values were observed inversely proportional to strength values. As expected for steels forged at 1250 °C, the lowest yield and tensile strength values were observed in 41Cr4 steel, while the highest tensile strength values were obtained in AISI 420 steel. On the other hand, the highest % elongation values were obtained in 41Cr4 steel.

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When 41Cr4, 42CrMo4 and AISI 420 notch impact test results forged at 800 °C were analysed, the highest fracture energy (impact energy) was obtained in 41Cr4 steel. The lowest fracture energy was observed in AISI 420 steel. When the notch impact test results were examined as a result of forging at 950°C, the lowest fracture energy value was obtained in 42CrMo4 steel, while the highest value was observed in 41Cr4 steel. When the fracture energy values obtained as a result of forging at 1250°C were analysed, the lowest value was obtained in 42CrMo4 steel, while the highest value was observed in AISI 420 steel. It is also seen that the fracture energy values of 41Cr4, 42CrMo4 steels are very close.

It is seen that the results obtained are compatible with microstructure and SEM images.

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