EFFECT OF DIFFERENT TEMPERING TEMPERATURES ON MECHANICAL PROPERTIES AND MICROSTRUCTURE OF MARTENSITIC STAINLESS STEEL

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ABSTRACT

The alloy steels are extensively used in every industry ranging from household utensils to the aerospace industry. This research work mainly focuses on the evaluation of the mechanical properties of martensitic stainless steel SS410 & SS420 materials subjected to tempering heat treatment process by various levels of temperature. Most of the martensitic steel is subjected to the tempering process to vary the mechanical properties like ductility & toughness is required for most of the applications varying from household utensils to the aerospace industry. Steel properties can vary to a great extent with even a small change in its chemical composition and temperature. The martensitic stainless steels SS410 & SS420 are subject to microstructure examination and the mechanical properties like hardness, tensile, and impact strength are evaluated for each specimen. The results are then compared with the untreated and heat-treated martensitic stainless steels SS410 & SS420 for the change in its microstructure and mechanical properties.

KEYWORDS: Martensitic Stainless Steel, Tempering, Microstructure Examination, Hardness, Tensile test & Impact test

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1. INTRODUCTION

Stainless Steel is a class of material that consists of two basic elements namely carbon and iron followed by many other secondary elements, it is extensively used in construction industry due to its high tensile strength and availability [1]. Steel is available in two crystalline forms namely (Body Centered Cubic and FaceCentered Cubic) as it is temperature dependant. The percentage of carbon can vary up-to 2.1% of its weight. Due to percentage variation, carbon is available in steel either as a solute or in precipitated form [2, 3]. Iron becomes ductile due to the dislocations this in turn controls the mechanical properties such as hardness, ductility, impact and tensile strength [4].

Stainless steel can be classified based on the alloying constituents which in turn controls the microstructure [5, 6]. Among the stainless steels, Austenitic type are weldable and extensively used in different industrial applications, not limited to food and chemical industries. They have a face-centered cubic structure [7].

Body Centered Cubic structure is observed in iron chromium alloys of Ferrite Stainless Steels [8, 9]. These steels are ductile and formable, however at elevated temperature their strength reduces. Some ferritic stainless steel are used in automotive, household and consumer applications [10]. Martensitic stainless steels also comprise of Ni, C, Mo, and Cr likely in composition with the ferrite group [11]. The austenitic structure is stable at elevated temperatures whereas the Martensitic structure is stable at room temperature. The sudden quenching is the only method to form martensitic crystal structure and this structure having high hardness, brittleness, and strength [12].

These properties are not suitable for structural applications. Hence, the ductility and toughness of the martensitic material can be improvised by the heat-treatment process. By varying the chemical composition, the mechanical properties can be enhanced [13-14], controlling microstructure, and subjected to the heat-treatment process. Tempering is necessary to enhance the machinability, refine grain size, refine grain structure, and relieve the internal stresses and which in turn increases ductility [14].

2. MATERIAL AND METHODS

2.1 Materials

The SS410 is a heat treatable martensitic chromium stainless steel. To develop a defect-free surface, melting practice is controlled. SS410 provides an excellent combination of wear corrosion resistance. It is also used in demanding medical accessories.

Table 1: Chemical Composition of SS410

Element	C	Si	Mn	P	S	Cr
Composition in %	00.128	00.581	00.675	00.039	00.031	12.591

SS420 Stainless steels comprises of various versions of grade 420 containing molybdenum, vanadium and sulphur, it also consists of grades of SS440. Martensitic stainless steels contain high carbon which leads to higher hardness. These steels are hardened and tempered during fabrication. At elevated temperature, these steels lose mechanical strength and at sub-zero temperatures, reduces ductility. This temperature dependence of Martensitic steels affects its operating conditions.

Table 2: Chemical Composition of SS410

Element	C	Si	Mn	P	S	Cr
Composition in %	00.185	00.566	00.704	00.026	00.029	12.485

2.2 Preparation of Test Specimen

Sets of test specimens were prepared for Hardness, Tensile, Impact, and Microstructural analysis. The following Table 3 shows standards used required to conduct the various tests.

Table 3: Standards used for Tests

Test Name	Test Standards
Tensile Test	ASTME-8
Charpy Test	BIS-1499

2.3 Methodology

Chart 1: Methodology Procedure.

Samples of SS410 and SS420 are selected for experimentation. Chemical composition and microstructure of the samples are found out respectively then Samples are forged at 900⁰c as shown in Figure 1 at 4 ton followed by oil soaking for one hour to impart hardness.

Figure 1(a): Forging Machine

Figure 1 (b): Forging Samples

Figure 2(a): Electrical Furnace

Figure 2(b): Oil Soaking Tank

The Electrical Furnace Capacity is 2000kg load, Temperature 800⁰c and 1000⁰c and Size 2050× 1860 ×1480 (D×W×H) as shown in Figure 2. The samples are oil quenched at 980⁰C. These Samples are tempered at different temperatures i.e. 300⁰c, 400⁰c, 500⁰c, 600⁰c, 700⁰c and 800⁰c respectively. Microstructure of the tempered samples are studied and compared to the original samples. Tempered samples are further machined to prepare test specimens as shown in Figure 4 and testing machines for tensile test and impact test as show in Figure 3.

Figure3 (a): Tensile Testing Machine

Figure 3(b): Impact Testing Machine

Figure 4(a): Impact Testing Specimen

Figure 4(b): Tensile Testing Specimen

3. RESULT AND DISCUSSIONS

3.1 Microstructure Examination

Optical metallurgical microscope (Model: Nikon epiphot 200) is used for microstructure examination of SS410 and SS420 material at various tempering temperatures. The microstructure examination is carried out at a magnification of 50 μ m. The Figure 5 and Figure 6 as shown, it clearly shows the presence of fine needle type martensitic microstructure before tempering heat treatment process.

Figure 5: Microstructure of SS410 Martensitic Material

Figure 6: Microstructure of SS420 Martensitic Material

Figure 7: Microstructure of Tempered Samples at 300⁰c Figure 8: Microstructure of Tempered Samples at 400⁰c Figure 9: Microstructure of Tempered Samples at 500⁰c Figure 10: Microstructure of Tempered Samples at 600⁰c

The martensitic samples are then subjected to heat treatment process (tempering). The tempered sample are subjected to microstructure examination and its clearly indicates from the Figure 7, Figure 8, Figure 9 & Figure 10 microstructure consists of fine spheroidized carbides in a ferrite matrix and carbides increase by increasing the tempering temperatures. It reduces the hardness of materials as shown in Table 4 and Graph 1.

3.2 Hardness and Tempering Temperatures for Materials SS410 and SS420

Table 4: Hardness Result Table for SS410 and SS420

Tempering Temperature in ⁰ c		300	400	500	600	700	800
Hardness in BHN	SS 410	352	344	369	287	221	230
	SS 420	430	420	450	350	270	280

Graph 1: Hardness & Tempering Temperature for Materials SS410 & SS420

The hardness of both SS410 and SS420 vary almost in the same fashion. As we increase the temperature from 300°C to 400°C this region being the recovery stage no significant atomic movements is observed. Then increase the temperature to 500°C the hardness of both materials reach its peak values Table 4 and Graph 1. The reason behind this is the phenomenon called “Tempered Brittleness” due to which the material becomes very hard. Further, increasing the tempering temperature shows a significant decrease in their hardness values. At high temperatures, the hardness starts decreasing and reaches an optimum value at 700°C. Among these two the values of SS420 is more having more carbon content than SS410.

3.3 Ultimate Tensile Strength for Materials SS410 and SS420

Table 5: Ultimate Tensile Strength Materials SS410 & SS420

Tempering Temperature in °C		300	400	500	600	700	800
UTS in N/mm ²	SS 410	1246	1245	1292	1240	651.55	583.8
	SS 420	1520	1500	1520	1550	785	695

Graph 2: Ultimate Tensile Strength & Tempering Temperature for Materials SS410 & SS420

The Ultimate tensile strength of SS410 shows almost constant values until 500⁰c so are the values of SS420 because of negligible atomic movements. The ultimate tensile strength depends on the hardness of the material and varies accordingly in Table 5. As soon as the temperature increases, the carbon present in the martensite starts coming out to form temper carbon which is combined with the ferrite called sorbite. This structure provides good ductility in the material by relieving the hardness and residual stresses present in the material and decreases. The steep decrease in Graph 2, Figure 7 & Figure 8 shows the sorbite formation which is soft in nature and has low UTS and hardness. Among the two types, SS420 values are always greater than the other one because of the carbon content is more.

3.4 Yield Strength Materials for SS410 and SS420

Table 6: Yield Strength Result Table for SS410 and SS420

Tempering Temperature in ⁰ c		300	400	500	600	700	800
Yield Strength in N/mm ²	SS 410	1009	1009	1053	1075	542.7	385.4
	SS 420	1230	1230	1270	1280	670	470

Graph 3: Yield Strength & Tempering Temperature for Materials SS410 & SS420

The Yield Strength of these materials increases up to 500⁰c and then suddenly decreases. This is because of the change in phase from martensite to sorbite Table 6 & Graph 3.

3.5 Percentage Reduction in Area of Materials SS410 and SS420

Table 7: % Reduction in Area Result Table for SS410 and SS420.

Tempering Temperature in ⁰ c		300	400	500	600	700	800
Reduction Area in %	SS 410	40	43.5	41	47	55	49
	SS 420	47	50	48	55	65	58

Graph 4: % Reduction in Area & Tempering Temperature for Materials SS410 & SS420

This property is inversely proportional to the above mentioned ones. In the elastic region, because of ductility, the reduction increases and at 500°C the value decreases because of tempered brittleness and above that temperature, the materials start losing its brittleness and this value increases until the point where it reaches its maximum value at UTS and then it reduces to the point of fracture Table 7 & Graph 4 where it breaks. Among SS410 and SS420 the latter has greater values than the former.

3.6 Charpy Energy of Materials SS410 and SS420

Table 8: Charpy Result Table for SS410 and SS420

Tempering Temperature in °C		300	400	500	600	700	800
Impact Energy in kg	SS 410	4.25	4.3	3.4	5.6	11.8	13.2
	SS 420	5	5	4	6.5	13	15

Graph 5: Impact Energy & Tempering Temperature for Materials SS410 & SS420

The impact strength of both the materials increases with an increase in tempering temperature 500⁰c being an exception because of an increase in brittleness. The material hardness decreases as soon as tempering temperature increases. It also increases the impact strength value. The maximum value of impact strength is at 800⁰c where the brittleness is minimum. The value of impact strength for both the types of material is nearly the same SS420 having a little bit of greater ones Table 8 & Graph 5.

3.7 % Reduction in length of Material SS410 and SS420

Table 9: % Elongation Result Table for SS410 and SS420

Tempering Temperature in ⁰ c		300	400	500	600	700	800
Reduction in Length %	SS 410	2.25	2.6	3.4	4.4	6.1	5.1
	SS 420	2.5	3	4	5	7	6

Graph 6: % Reduction in Length & Tempering Temperature for Materials SS410 & SS420

It has ductility but as it reaches the UTS point, the ductility decreases entering into the plastic region and from the UTS point, the same starts decreasing as it forwards to the fracture point. Until the UTS point the elongation continues and necking appears to be happening and after UTS and recrystallization temperature (720⁰c), the bonds starts breaking and fracture occurs. The elongation is more among SS420 than in SS410 Table 9 & Graph 6.

4. CONCLUSIONS

The results of the experiments showed that as we increase the tempering temperature, there is a certain region where the hardness of the material reaches its peak value. This is because of the phenomenon called 'Tempered Brittleness', due to which the material becomes very brittle. Further increasing the temperature will gradually decrease the hardness. So for SS410 and SS420, this region being around 500⁰c it should be avoided and the temperatures for tempering should be chosen accordingly.

For different applications the properties needed from these materials are also different, to attain that, one can only alter them using different heat treatment processes and among these processes tempering is the only process through which

we can impart impact strength to the material.

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