Effects of Certain Rates (0.5%, 2.5%, and 5%) Strain Hardening on Fatigue Life of S420 Quality Reinforcing Steel

M. Mevlüt KARACA*, Alper İNCESU+

*Mechanical Engineering, Karabuk University
Karabuk, Turkey
mmevlutkaraca@karabuk.edu.tr

+Metallurgical and Materials Engineering, Karabuk University
Karabuk, Turkey
alperincesu@ karabuk.edu.tr

***Abstract*— In this study, three different pre-straining processes, 0.5%, 2.5% and 5%, were applied to S420 quality reinforcing steel. Tensile test at room temperature (23±5 ºC) was applied to the pre-strained and non-pre-strained specimens. A new yield point was formed and yield strengths decreased by 0.2%, increased by 0.81% and increased by 17.68% under pre-straining conditions of 0.5%, 2.5% and 5%, respectively. In addition, samples with the same pre-strain ratios and samples without pre-straining are applied at the load values determined according to ISO 15630-1 fatigue standards (TS 708:2016 S420-B420B,C and B500B, C), at room temperature (23±5 ºC), about 55 Hertz frequency and Fatigue testing was performed on 10 million (high cycle) target cycles. The non-pre-strained specimen withstands 10,000,000 cycles without breaking under its own loading conditions (TS 708:2016 S420-B420B,C). Under one step higher loading conditions (TS 708:2016 B500B,C), the pre-strained samples (at 0.5%, 2.5% and 5% prestress ratios) can withstand 10,000,000 cycles without breaking, while the non-pre-strained sample can withstand 6,030,235 cycles. has been broken. For this reason, according to the TS 708:2016 standard, S420 quality reinforcing steel, a higher quality steel value has been reached after the pre-straining application and the fatigue life has been increased.**

***Keywords*— strain hardening, work hardening, pre-strained reinforced steel, fatigue test, high cycle fatigue test, S420 steel**

I. INTRODUCTIONS

Fatigue, which is frequently seen among the causes of fracture in materials, occurs under cyclic loads, starts with the formation of one or more cracks, and grows until it causes failure [1].

The fatigue behavior of materials depends on their strength values and plasticity properties. Fatigue behavior consists of two stages: crack formation and crack propagation [2]. In high-cycle fatigue, crack initiation accounts for a large portion of the total fatigue life relative to crack propagation. Therefore, the fatigue life in crack propagation is negligible. In low-cycle fatigue, both crack initiation and crack propagation are important and are included in the fatigue life. It is thought that increasing the strength will improve the process up to the crack initiation [3-4].

High-cycle fatigue is stress-controlled and is performed with low amplitudes mostly in the elastic region. The number of cycles is more than 10^4 [5]. Low-cycle fatigue is strain-controlled and is performed at high amplitudes in both the elastic and plastic regions. The number of cycles is less than 10^4 [6].

Mechanical fractures are complex problems that depend on ambient temperature, corrosion, load, and time. The applied loads can be fixed, variable, uniaxial, or multiaxial. Reload time can be in milliseconds like a bullet fired from a gun, or it can last for years or centuries, like bridges [7].

Under static or dynamic loading, structural members can be damaged and fail. Reinforced concrete steels, which are frequently used in concrete structures such as bridges, marine structures, parking lots, are exposed to fatigue loads throughout their lives. Therefore, it is important to understand the creep and fatigue behavior of these steels. Boundary conditions should be considered in fatigue behavior. The main variable causing fatigue damage in steels and composite materials is the range of applied stress [8].

When a material is subjected to deformation, the orderly array of atoms is disrupted and dislocations. These dislocations continue until there is an arresting effect. Dislocations can overlap and stack on top of each other. This confusion provides an increase in strength by preventing the deformation effect in the material. However, this increase in strength reduces ductility and formability [9].

Strain hardening is when a ductile metal becomes stronger as a result of plastic deformation. It is usually carried out at room temperature. In the stress-strain curve in Figure 1, while the first yield point of the material is σ_{y0}, when the load is applied and released to the D point bypassing the material's yield point, the new yield point will be σ_{yi} and the material will become more durable [10].

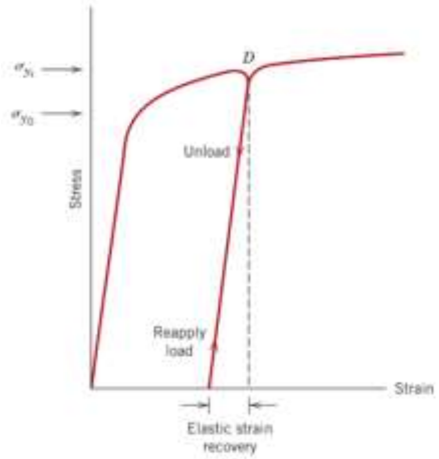

Fig. 1. Strain hardening, formation of new yield point [10]

Table 1 shows typical examples and applications of various types of structural steel. When S420 steel is examined, it is seen that the yield strength value is between 420-600 MPa. This type of steel is generally used in bridges and high-rise buildings.

TABLE I
TYPICAL EXAMPLES AND APPLICATION OF VARIOUS STRUCTURAL STEEL TYPES [11]

Yield strength (MPa)	Type	Other description	Typical examples	Potential application
<420	Mild Steel	Regular structural steel	S235, S275, S355	Buildings
420-600	Conventional high strenght steel (CHSS)	High performance steel/high tensile steel	S420, S460, S550	Bridges, high rise buildings
690-1100	Very high strength steel (VHSS)	Ultra high strength steel/super high strength steel	S690, S890, S960, S1100	Cranes, bridges, high rise buildings, offshore structures

In this study, S420 quality construction steel was subjected to the tensile pre-strain at a ratio of 0.5%, 2.5%, and 5%. Then, tensile test, high cycle fatigue test, and fracture surface analysis were applied to understand the effect of the pre-strain application on the mechanical properties of S420 quality construction steel.

II. MATERIAL AND METHODS

In the experimental study, first of all, 16 mm diameter S420 quality reinforced concrete steel was subjected to a tensile test at room temperature without prestressing. Then, 0.5%, 2.5%, and 5% pre-strained and new yield strength points were formed, respectively. Tensile test was applied to the prestressed steels and the yield strength, tensile strength, and elongation values were noted until the material broke.

For the tensile test, a Zwick Roell Z600 model, shown in Figure 2, with a load capacity of 600 kN, was used. Tensile tests were performed at room temperature (23±5 ºC). The test was carried out with a tensile speed of 0.0067 1/s and a test length of 290 mm.

Fig. 2. Zwick/Roell Z600 testing machine

For the fatigue test, new samples were prepared and pulled without breaking with 0.5%, 2.5%, and 5% pre-strain, respectively. Three pre-strained specimens and one non-pre-strained specimen were molded with iron powder, hardener, accelerator, and resin to make them ready for the fatigue test. The samples were not notched. The fatigue test was carried out at room temperature (23±5 ºC) at a frequency of approximately 55 Hz (Hertz) and 10 million (high cycle) target cycles. Stress ratio R=0.39 and R=0.49 values based on tensile-tensile repetitive loading was performed. Table 2 shows other parameters of fatigue.

As shown in Table 2, first of all, a fatigue test was performed without prestressing at static and dynamic load values of S420-B420B/C quality steel in accordance with TS 708:2016 standard. Then, the static and dynamic load values of B500B, C steel, which is top-quality steel, were cycled to the prestressed samples.

TABLE II
FATIGUE TEST PARAMETERS

Specimen designation	Load Values (TS 708 2016)	F_s kN	F_d kN	$\sigma_{min.}$	$\sigma_{max.}$	R
Normal	S420-B420B/C	35,18	15,08	50,26	20,10	0,39
0.5% pre-strain	B500B,C	45,23	15,08	60,31	30,15	0,49
2.5% pre-strain	B500B,C	45,23	15,08	60,31	30,15	0,49
5% pre-strain	B500B,C	45,23	15,08	60,31	30,15	0,49
Normal	B500B,C	45,23	15,08	60,31	30,15	0,49

Fatigue tests were performed using the Zwick/Roell Amsler500 HFP5100 Magnetic Resonance Fatigue Tester shown in Figure 3 under push-pull loading conditions.

ZWICK/ROELL Amsler HFP 5100 is a magnetic resonance fatigue testing machine which has 500 kN(50 tones) force application capacity. With the help of magnets that are within the machine, it produces magnetic resonance waves as a result fatigue tests can be done at high frequencies. Fatigue tests were carried out in accordance with ISO 15630-1 standards.

Fig. 3. Zwick/Roell Amsler500 HFP5100 testing machine

III. EXPERİMENTAL RESULTS

Tensile test results are shown in Table 3 as yield strength (ReH), tensile strength (Rm), and elongation at break (A). In addition, the results are graphically shown in Figure 3.

TABLE III
MECHANICAL PROPERTIES OF S400 STEEL

Specimen designation	ReH MPa	Rm MPa	A %
normal	492	649	19,2
0.5% pre-strained	491	638	18,6
2.5% pre-strained	496	645	16,4
5% pre-strained	579	647	13,2

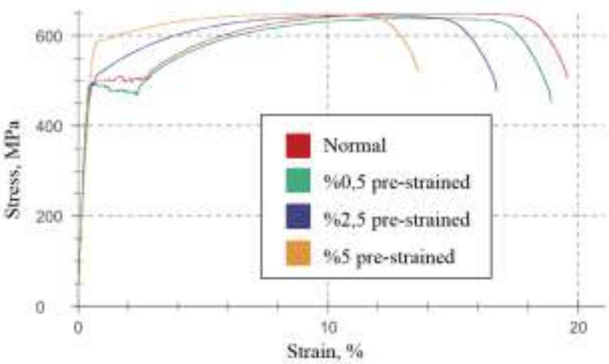

Fig. 4. Tensile test results (Stress-Strain Curves)

The results of the fatigue test are given in Table 4 as load values, the desired number of cycles, maximum achieved cycles, static force (Fs), and dynamic force (Fd).

TABLE IV
FATIGUE TEST RESULTS

Specimen designation	Load Values	Number of Cycles	Max Driven Cycles Per Specimen	F_s kN	F_d kN
Normal	S420-B420B/C	10.000.000	10.000.050	35,18	15,08
0.5% pre-strain	B500B, C	10.000.000	10.000.005	45,23	15,08
2.5% pre-strain	B500B, C	10.000.000	10.000.007	45,23	15,08
5% pre-strain	B500B, C	10.000.000	10.000.012	45,23	15,08
Normal	B500B, C	10.000.000	**6.030.235**	45,23	15,08

While all samples were successfully completed without breaking or deforming in the target of 10 million cycles, in the unstrained sample, B500b was able to withstand up to 6,030,235 cycles at the load values of the steel. The surfaces of this sample, which broke off ductility as a result of fatigue, are given in Figure 5. There are two regions that appear different from each other in the section. Crack initiation has occurred on the left side, that is, on the smooth and granular part. On the other side, the smooth part, there was a sudden rupture.

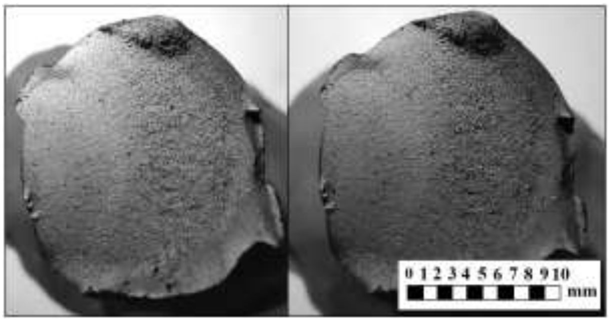

Fig. 5. The surface of the broken specimen (6.030.235 cycle)

CONCLUSIONS

In this study, the effect of pre-stain applied to S420 quality reinforced steel on fatigue was investigated. The results obtained from this study can be summarized as follows:

1. Yield strengths decreased by 0.2%, increased by 0.81% and increased by 17.68% at 0.5%, 2.5% and 5% prestressing conditions, respectively.
2. Tensile strengths remained approximately the same under prestressing conditions.
3. As can be seen from Table 4, S420 quality steel has withstood 10,000,000 cycles without breaking under its own

loading conditions (TS 708:2016 S420-B420B,C). Under one step higher loading conditions (TS 708 2016 B500B,C), the prestressed samples (at 0.5%, 2.5% and 5% pre-strain ratios) can withstand 10,000,000 cycles without breaking, while the non-pre-strained sample broke in 6030235 cycles. Therefore, according to the TS 708:2016 standard, S420 quality reinforcement steel shows that a higher quality steel value has been reached. For this reason, according to the TS 708:2016 standard, S420 quality reinforcement steel has reached a higher quality steel value after the pre-straining application and the fatigue life has been increased.

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