PERFORMANCE EVALUATION OF S700MC AND ST52 STEELS IN TERMS OF MECHANICAL PROPERTIES AND FATIGUE LIFE

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Abstract

This paper aimed to investigate the advantages of the use of S700MC steel instead of St52 steel widely used in industrial areas. For this purpose, a tensile test, a macro hardness test, a Charpy impact test, and a fatigue life test were performed on St52 steel and S700MC steel specimens. Test results showed that S700MC steel generally exhibited better performance than St52 steel in terms of mechanical properties and fatigue life. In addition, a finite element method (FEM) analysis was conducted on a tandem housing body of a motor grader according to S700MC and St52 scenarios to determine their safety factors and the reduction in its weight with the use of S700MC steel. FEM results showed that the use of S700MC steel led to an increase in the safety factor by about 83 % or a decrease in the weight by about 30 %.

Keywords: St52, S700MC, FEM, mechanical testing

1. INTRODUCTION

Fuel economy and lifetime improvements are two most important issues for heavy-duty machinery designers. Fuel consumption and emissions can be reduced by lightweight design; on the other hand, lifetime can be prolonged by using new materials [1, 2].

The usage of low density materials can be a solution for weight reduction. For this purpose, aluminum and magnesium alloys are preferred by many researchers in many engineering applications. Fındık and Turan [3] designed lighter wagon by taking into consideration density, cost, specific stiffness, corrosion and wear resistance properties of materials. They optimized the design by using aluminum instead of steel. Solazzi [4] designed boom and arm of an excavator by substituting the steel alloy for an aluminum alloy to increase the productivity of the excavator. Although usage of low density materials is an effective method for weight reduction, mechanical properties of such materials are insufficient for critical parts of heavy-duty machinery exposed to harsh conditions.

Steel is one of the most appropriate and cost effective material to use in heavy-duty machinery. Lightweight design in steel parts can be applied by different means. Polami et al. [5] investigated the effect of joining method on lightweight design of heavy-duty trucks. They studied on drive pinion part and obtained 14 % weight reduction by joint-site structure friction welding method. Yıldırım et al. [6] reported that the mechanical post-weld treatment processes affected the lightweight design by providing additional fatigue strength. They increased the fatigue strength of S700 steel by high-frequency mechanical impact treatment and made contribution to weight reduction.

Preference of high-strength steels instead of normal steel is the most effective method for both weight reduction and strength improvement. Mela and Heinisuo [7] compared the performance of S500 and S700 high strength steels with S355 normal steel. They achieved weight reduction up to 34 % by employing high strength steel. Furthermore, high strength steel usage becomes more economical in high-load conditions [7, 8].

Literature survey showed that reduction in weight and enhancement in strength can be achieved using alternative materials instead of conventional use of materials in applications. The objective of this study is to assess the suitability of the use of S700MC steel instead of St52 (corresponds to S355) steel in tandem housing body of a motor grader. Mechanical properties of these steels were compared by some mechanical tests. Furthermore, a finite element method (FEM) analysis was conducted on the tandem housing body to observe the weight and strength changes according to S700MC and St52 scenarios.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

2.1. Materials

Table 1 shows chemical composition of used steels. When comparing the percentage of alloying elements for St52 and S700MC steels, it is seen that S700MC steel has more percentage rate of some principal alloying ingredients which enhance mechanical properties of materials. For example, S700MC has 55 % higher Mn which improves the strength and hardness, 675 % higher Cr which improves strength, hardness, wear resistance and corrosion resistance and 3920 % further Mo which enhances toughness and hardenability [9]. These principal alloying elements also are carbide forming elements for better hardness and abrasive wear resistance.

Table 1 Chemical compositions of test materials

Steel grade	Elements (wt %)												
	C	Si	Mn	P	S	Al	Ti	V	Cu	Ni	Cr	Mo	Nb
St52	0.165	0.095	1.354	0.014	0.006	0.042	0.016	0.002	0.017	0.018	0.04	0.005	0.03
S700MC	0.12	0.3	2.1	0.009	0.002	0.015	0.021	0.01	0.1	0.04	0.31	0.201	0.09

2.2. Experimental procedure

For each test, the test specimens were prepared according to relevant test standards. After tests, the steels were compared in terms of their mechanical properties and fatigue life. In order to obtain accurate values, each test was repeated three times and study results were accepted as mean value of these test results.

2.2.1. Mechanical tests

To determine the yield strength, tensile strength and elongation of steels, tensile tests were performed on ALSA 20x2 MCK tensile tester with test speed of 10 mm / min. Tensile test specimens were prepared according to EN ISO 6892-1 standard. **Figure 1** shows dimensions of a tensile test specimen.

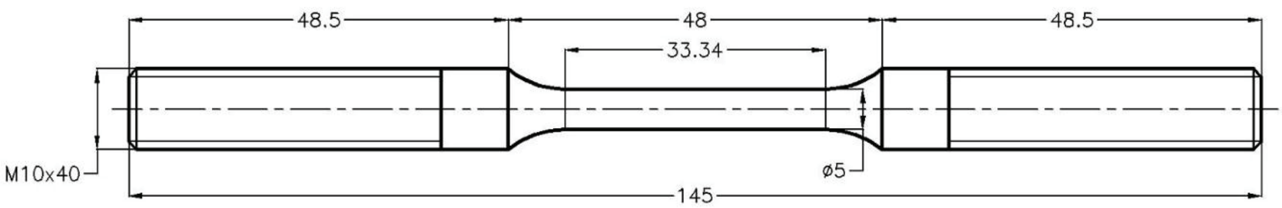

Figure 1 Dimensions of a tensile test specimen

Macro hardness values were measured by Qness Q750 MS macro hardness tester. Charpy impact tests were performed by TIME impact tester with load capacity of 300 Joule. The geometry of Charpy impact test specimens and test conditions were determined according to EN ISO 148-1:2010 standard. Fatigue life tests were conducted on rotating bending fatigue tester under frequency of 50 Hz. In order to obtain S-N curves of St52 and S700MC steels, seven different stress values were used (252 MPa, 264 MPa, 276 MPa, 300 MPa, 402 MPa, 504 MPa and 600 MPa). Fatigue test specimens were prepared according to ASTM E466 and ASTM E468 standards. **Figure 2** shows dimensions of the fatigue test specimen.

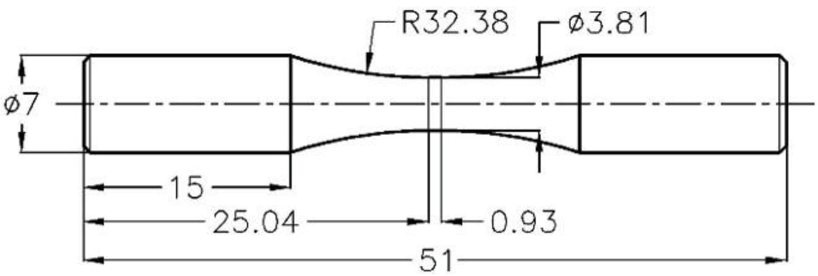

Figure 2 Dimensions of fatigue life test specimen

2.2.2. FEM analysis

After tests, the performances of St52 and S700MC steels were also tested (**Figure 3**) by using a finite elements analysis software (ANSYS) on tandem housing body of a motor grader. While planning FEM analysis, some data obtained from literature survey and manufacturers' catalogue was entered into ANSYS software to obtain realistic results. For instance, motor grader's weight is 14 tons, 80 % of total weight of motor grader is loaded on tandems and motor grader has two tandems and they carry this load equally. The solid model of the tandem housing was simplified in order to avoid possible analysis errors.

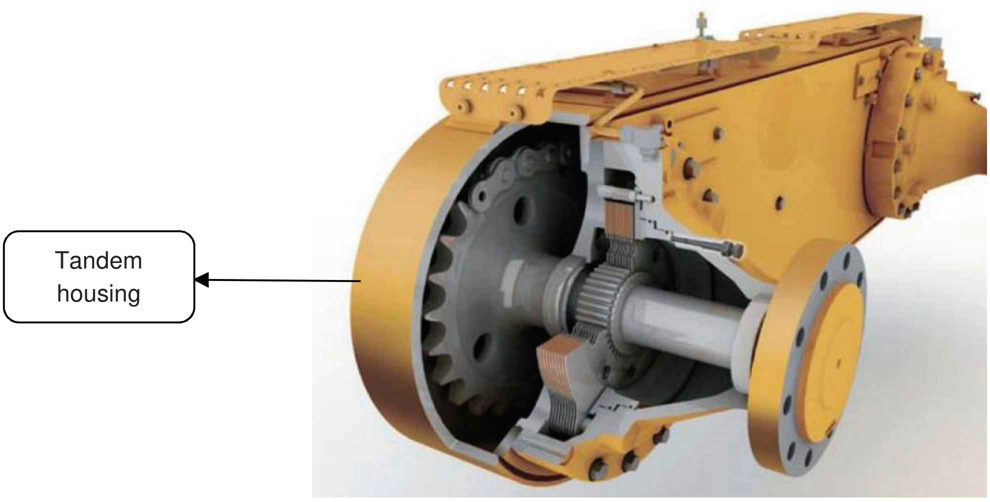

Figure 3 Cross-sectional view of a tandem [10]

3. RESULTS AND DISCUSSION

3.1. Tensile tests

Tensile tests results showed that, tensile strength values are 559.72 MPa and 869.90 MPa for St52 and S700MC respectively. The tensile strength of S700MC is higher by 49.52 % than that of St52. The elongation value of S700MC (12.15 %) also is lower by about 13 % than St52 (13.78 %). This case can be attributed to increasing hardness and strength of S700MC due to its fine grained microstructure and alloying elements. The hardness measurements confirmed this claim. According to tensile test results, tensile strength and elongation values of S700MC and St52 steels were in a good agreement with literature studies [11, 12]. **Figure 4** shows the stress-strain curves of St52 and S700MC steels.

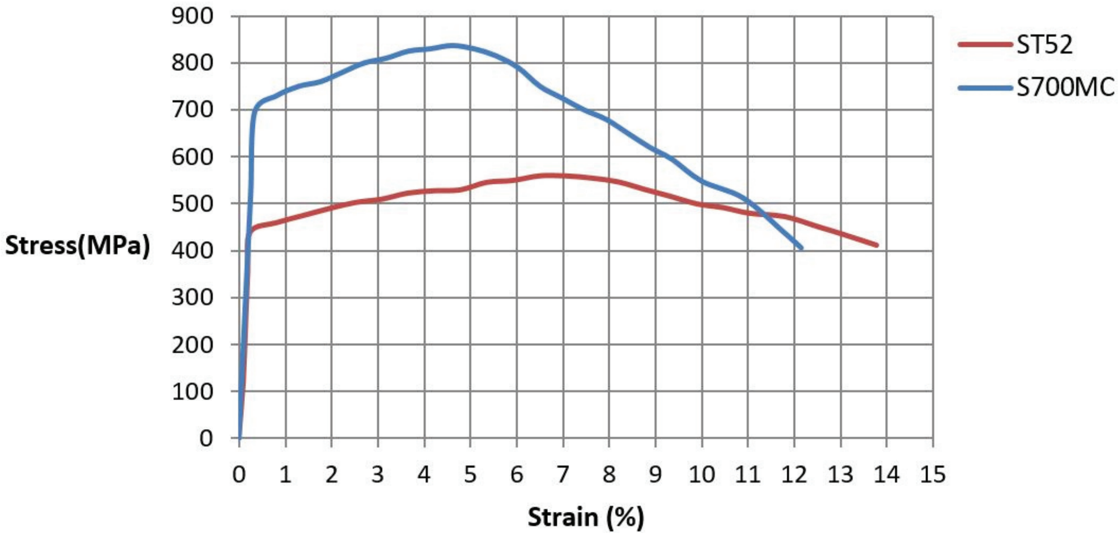

Figure 4 Stress-Strain curves of St52 and S700MC

3.2. Macro hardness test

According to macro hardness test results, hardness values of St52 and S700MC were found 161 HB and 255 HB respectively. An increase in the hardness is mainly related to grain size and alloying elements such as Cr, Mn, Mo and Ni (**Table 1**). Finer grain sizes positively affect the mechanical properties such as yield strength and tensile strength of steels due to limited dislocation motions and it is generally preferable from a design viewpoint because smaller grain size means higher strength and hardness [9]. It can be seen from **Figure 5** that grain size of St52 is larger than that of S700MC; therefore, it can be said that S700MC has better mechanical properties than St52.

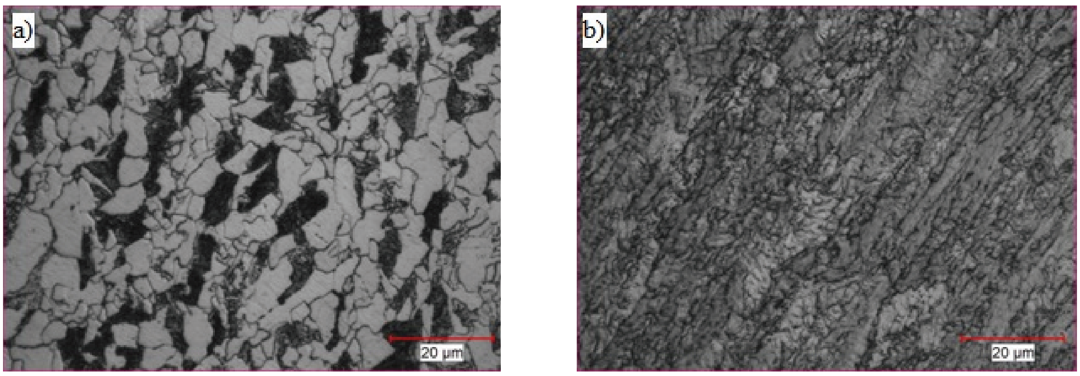

Figure 5 Microstructures of test specimens a) St52, b) S700MC

3.3. Charpy impact tests

According to impact test results, the fracture toughness values of S700MC and St52 steels were 147.43 J / cm^2 and 204.93 J / cm^2, respectively. The toughness of St52 was found to be higher by 39 % than that of S700MC due to higher hardness, yield strength and lower ductility of S700MC. In case of applications being subject to only excessive impact loads, St52 is more suitable material than S700MC.

3.4. Fatigue life tests

Fatigue limit stress values were 252 MPa and 204 MPa for S700MC and St52 steels, respectively (**Figure 6**). S700MC is better by 23 % than ST52 in terms of fatigue life at fatigue limit. It was found that the fatigue life test results comply with other research works in literature [13, 14]. According to Jesus et al. [15] high strength steels have higher resistance to fatigue crack initiation than the S355 steel because of higher strength properties. However, the fatigue crack propagation resistance is lower for high strength steels than S355.

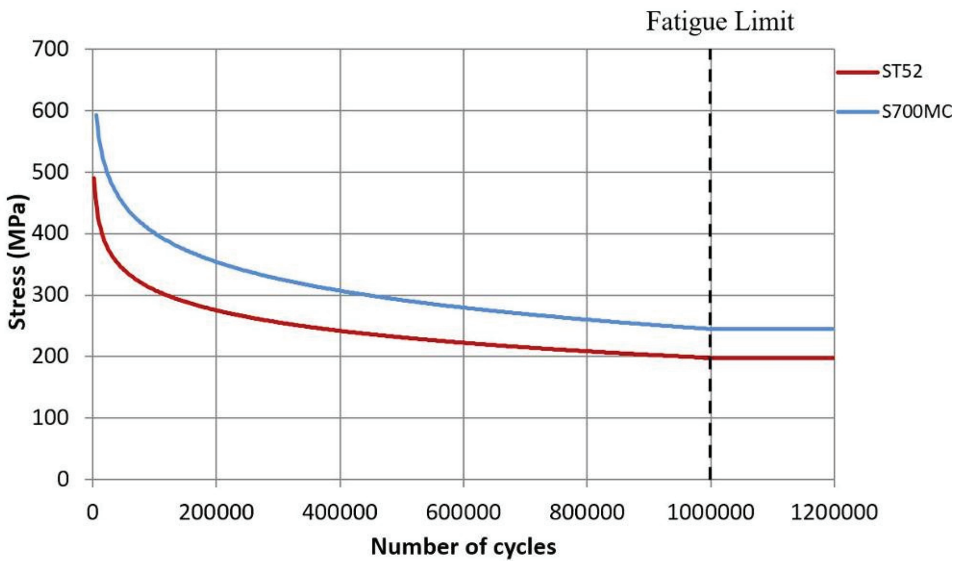

Figure 6 S-N curves of St52 and S700MC steels

3.5. FEM Analysis

According to assumptions mentioned above, **Figure 7** shows static analysis results of tandem housing body. After testing these steels by using ANSYS software, two conclusions were reached. One of these was conducted to compare the strength results. After testing both materials for original tandem housing dimensions, factors of safety (FS) for two cases were compared and it was found that when using S700MC steel, FS increased from 2.35 to 4.30. The other was conducted to investigate weight reduction by using S700MC instead of St52. When using S700MC with thickness of 12 mm instead of 16 mm in FEM analysis it was found that weight of tandem housing decreased from 319.5 kg to 219 kg and FS remained unchanged (about 2.35).

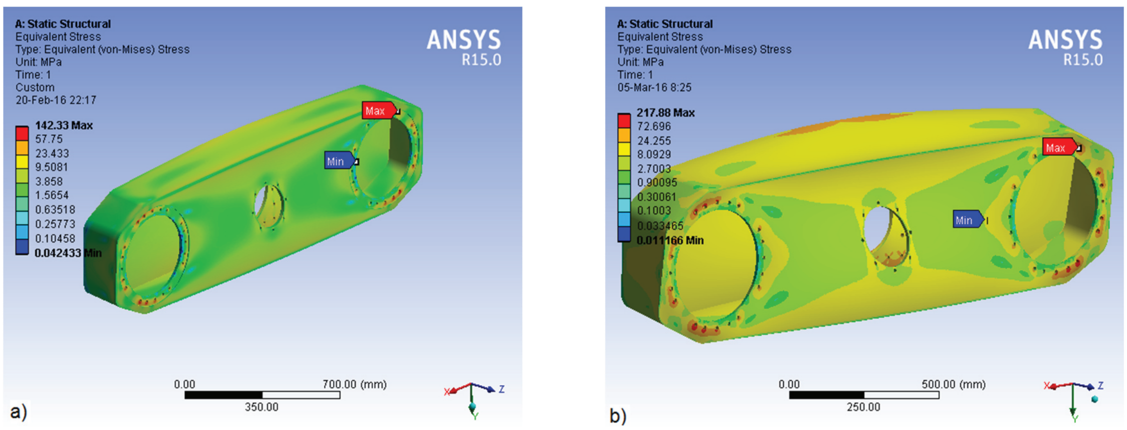

Figure 7 Static analysis results of tandem body a) St52 b) S700MC

4. CONCLUSION

In this study, performance evaluation of S700MC and St52 steels in terms of mechanical properties and fatigue life were investigated and a FEM analysis was conducted to compare strength values and to determine weight reduction. It was found that S700MC generally has superior mechanical properties in comparison to those of

St52. With use of S700MC, an increase of 83 % in FS and a decrease of about 30% in weight of tandem housing were provided. The test results showed that S700MC is more suitable to high load and harsh conditions of heavy duty machinery. Furthermore, FEM analysis results revealed that using S700MC steel instead of St52 steel is a way to increase strength and decrease weight.

ACKNOWLEDGEMENTS

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