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Analysis of Tempering Treatment on Material Properties of DIN 41Cr4 and DIN 42CrMo4 Steels

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DIN 41Cr4 and DIN 42CrMo4 materials have been widely used in automotive driving elements. Although 42CrMo4 is more expensive than 41Cr4, it is more preferable in terms of material properties. In this study, these two materials were heat treated by austenitizing in a continuous furnace at 850 °C and quenched in oil at 90 °C. After they were tempered at various temperatures, mechanical properties were determined for each tempering temperature. The material properties for both materials were compared with each other. Results indicated that same mechanical properties for 41Cr4 and 42CrMo4 can be achieved by tempering 41Cr4 about 50 °C lower temperature than for 42CrMo4. In addition to the mechanical tests, fatigue tests were performed for both materials. Weibull distributions were plotted. Results indicated that 42CrMo4 had a longer life than 41Cr4 material.

Keywords DIN 41Cr4, DIN 42CrMo4, fatigue, heat treatment, tempering, Weibull distribution

1. Introduction

DIN 41Cr4 (AISI 5140) and DIN 42CrMo4 (AISI 4140), which are low-alloy steels, have been widely used in automotive driving elements such as crankshafts, front vehicle axles, axle journals, and steering components. These materials are heat treatable and good for cold forging applications (Ref 1). 41Cr4 has been extensively used in automotive applications. 42CrMo4 is usually preferred when high strength is required. The material properties and fatigue behavior of 42CrMo4 are better than those of 41Cr4 (Ref 2, 3). The material cost changes based on material size. In addition to this information, 42CrMo4 is more expensive than 41Cr4.

Fatigue of 42CrMo4 was studied previously because of its temperability (Ref 4-6). Moreover, a simulation study of quenched and tempered steel (41Cr4) was done by Smoljan.[7] Both of the materials used in this study (41Cr4 and 42CrMo4) were medium-carbon steels. These alloys can be heat treated by austenitizing, quenching, and tempering to improve their mechanical properties. They are most often used in tempered condition having a tempered martensite microstructure. After the tempering, brittle nature of the martensitic steel can be overcome.

These alloys can be heat treated much easily by the additions of chromium (41Cr4 and 42CrMo4) and molybdenum (42CrMo4), which gives a variety of strength and ductility combinations. More importantly, addition of molybdenum into medium-carbon steels overcomes the temper embrittlement of these steels.

To the best of the authors' knowledge, no study was found in the literature focusing directly on the comparison of mechanical properties of 41Cr4 and 42CrMo4 alloys after austenitizing, quenching, and tempering. In this experimental study, several specimens were prepared from 41Cr4 and 42CrMo4 steels. Materials were first austenitized at 850 °C and then quenched in oil at 90 °C. After the quenching, each specimen was tempered at various temperatures. Tensile tests were performed in order to determine the lower yield strength, upper yield strength, and ultimate tensile strength of the materials. In addition to tensile test, hardness and fatigue life tests were also conducted. The present study compared, for the first time, all of these results for both materials.

2. Materials and Experimental Procedure

In this research, the material properties of 41Cr4 and 42CrMo4 low-alloy steels were investigated after tempering treatment. The chemical compositions of these materials were summarized in Table 1 (Ref 2). As seen from Table 1, the only difference between chemical compositions of these two steels is the presence of Mo in 42CrMo4.

For each material, 15 specimens were prepared with a diameter of 10 mm for each material. The test specimen geometries are given in Fig. 1. First, these test specimens were austenitized at 850 °C in a continuous heat treating furnace. Then, they were quenched at 90 °C in oil. The materials were tempered at 450, 500, 550, 600, and 650 °C for 1 h, respectively, followed by slow cooling. Three specimens for each material were used for each tempering temperature.

Tensile and hardness tests were performed for the specimens in order to determine the mechanical properties after the tempering. A universal tensile testing machine with a 600 kN capacity was used for the tensile testing of the materials. A Rockwell-C testing system was used for hardness measurement.

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Table 1 Chemical composition of the materials, wt.%

Material	C	Si	Mn	P	S	Cr	Mo	Ni
41Cr4	0.38-0.45	≤0.40	0.60-0.90	≤0.035	≤0.035	0.90-1.20	...	...
42CrMo4	0.38-0.45	≤0.40	0.60-0.90	≤0.035	≤0.035	0.90-1.20	0.15-0.30	...

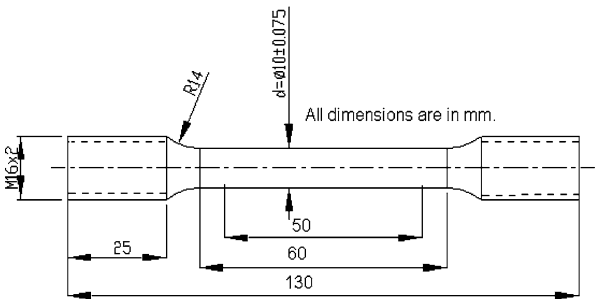

Fig. 1 Tensile test specimen geometries

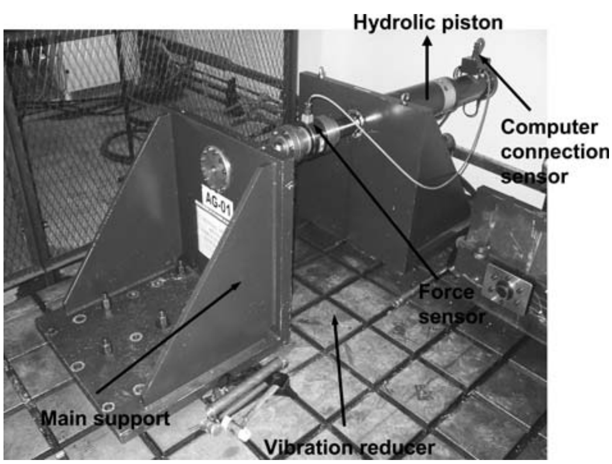

Fig. 2 Dynamic test station

An extensometer was used to measure the strain in the tension direction. Materials were pulled out until fracture.

A SERVOTEST brand dynamic test station was used to determine the fatigue life of the materials (Fig. 2). The test station was one directional. Therefore, the load was applied only on one direction. The shape of the test samples was different than that of the tensile test samples. They were actually in ball joint shape as seen in Fig. 3. It was exactly prepared as used in the cars to simulate the actual working conditions. These ball joint samples were tempered at 650 °C for 80 min. The loading details are presented in Fig. 3. The materials were cycled until failure. The range of the applied forces was between +9150 and −3350 N and the frequency was 7 Hz. Nine test samples were tested for each steel.

Weibull diagram shows a relationship between the probability of survival and life.[8] Fatigue lives were plotted as a straight line on Weibull coordinates (log-log vs. log), so that the life of these materials at any reliability level can be determined. The Weibull plots for fatigue failure were plotted for both materials in the same plot.

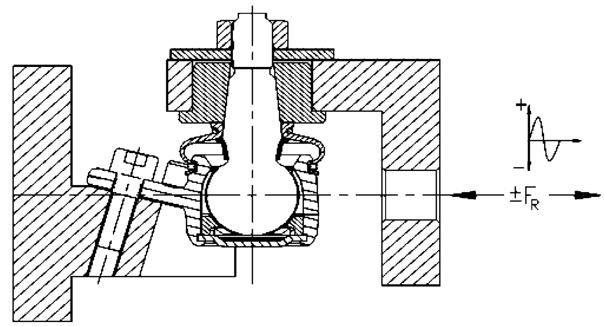

Fig. 3 Ball joint test setup detail

3. Results and Discussion

As mentioned in the previous section, the specimen at each tempering temperature was tested until fracture. The test was repeated for three specimens to check the accuracy of the test and the data were recorded. Upper yield point (UYP), lower yield point (LYP), ultimate tensile strength (UTS), and total elongation (TE) were determined using the tensile test data.

In most of the engineering applications, the yield point of a material has been considered as the limit to the failure. Exceeding the yield point, a permanent deformation on the material occurs. In the automotive front equipment, the life calculations are made by using this limit. The stress formed on the parts should be much lower than the yield point of the material used in the front equipment. The comparison of lower and upper yield points of the 41Cr4 and 42CrMo4 materials are summarized in Fig. 4 and 5. As seen in these figures, 42CrMo4 steel has greater LYP and UYP values than the 41Cr4 steel after the each tempering temperature. However, it was also observed that it was possible to get closer mechanical properties (LYP and UYP) to temper the 41Cr4 steel at a roughly 50 °C lower temperature than the tempering temperature of 42CrMo4. Figures 4 and 5 clearly indicated that there was a linear relationship between the materials, based on the tempering temperature. LYP and UYP results clearly showed that the more economic material (41Cr4) can be used instead of the more expensive material (42CrMo4) after the tempering. It is known that millions of cars are manufactured every year. Reducing the price without compromising the durability and quality is a very important aspect of the manufacturing.

Ultimate tensile strength for both of the materials is also compared with each other as seen in Fig. 6. 42CrMo4 material had greater UTS than 41Cr4 material after each tempering temperature. It is not possible to get 42CrMo4's UTS to temper 41Cr4 at lower tempering temperatures as shown in Fig. 6. Although it was compared in this study, UTS data were not used in structural calculations during the design stage. Figure 7 shows the comparison for total elongation (TE) of both of the materials. 41Cr4 material had more elongation than 42CrMo4

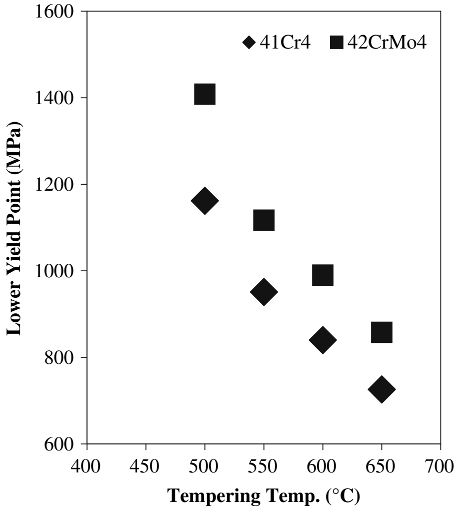

Fig. 4 Lower yield point vs. tempering temperature

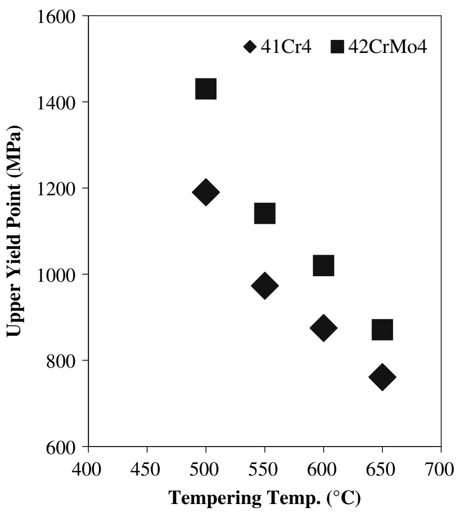

Fig. 5 Upper yield point vs. tempering temperature

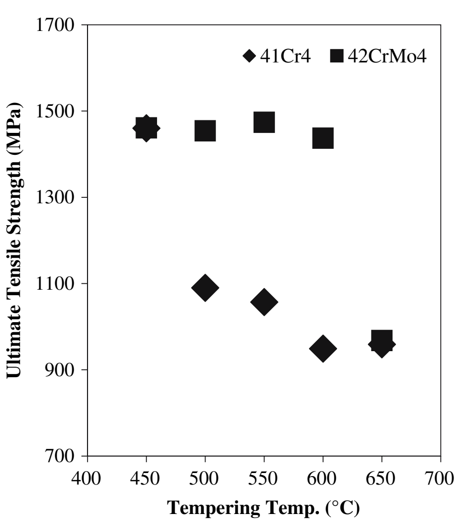

Fig. 6 Ultimate tensile strength vs. tempering temperature

(Fig. 7). From these results, we can assume that no temper embrittlement of these steels, especially for 41Cr4, was observed. This shows that 41Cr4 could be a good alternative to 42CrMo4 to be used in the automotive parts. It seemed that the tempering temperatures between 500 and 650 °C had no great effect on TE of 41Cr4 steel. However, there was a considerable effect after the tempering at 450 °C. Furthermore, there was no considerable effect for 42CrMo4 material between 450 and 600 °C of tempering temperatures ranges except between 600 and 650 °C.

Hardnesses of both of the materials were also determined after each tempering temperature. After the quenching, these materials had a martensitic structure and it was brittle. To remove the brittle nature of martensitic structure of these steels, they were tempered and cooled to room temperature very slowly to overcome the temper embrittlement. Figure 8 indicated that 42CrMo4 had higher hardness values than 41Cr4 after each tempering temperature. However, the same situation was also observed for this measurement like UYPs and LYPs.

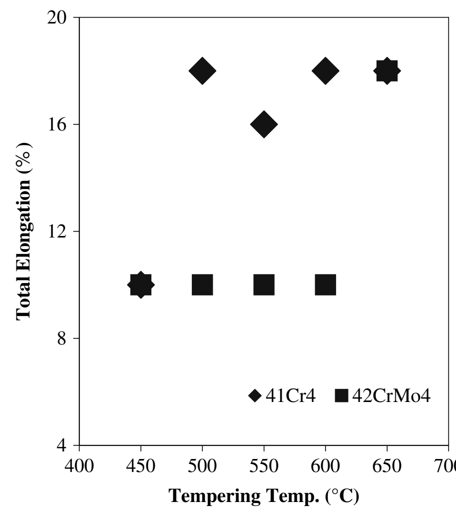

Fig. 7 Total elongation vs. tempering temperature

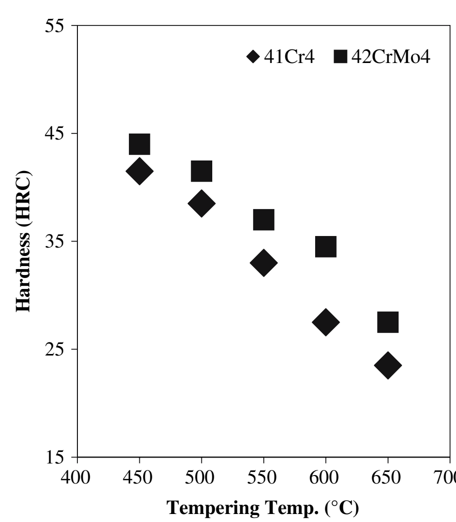

Fig. 8 Hardness vs. tempering temperature

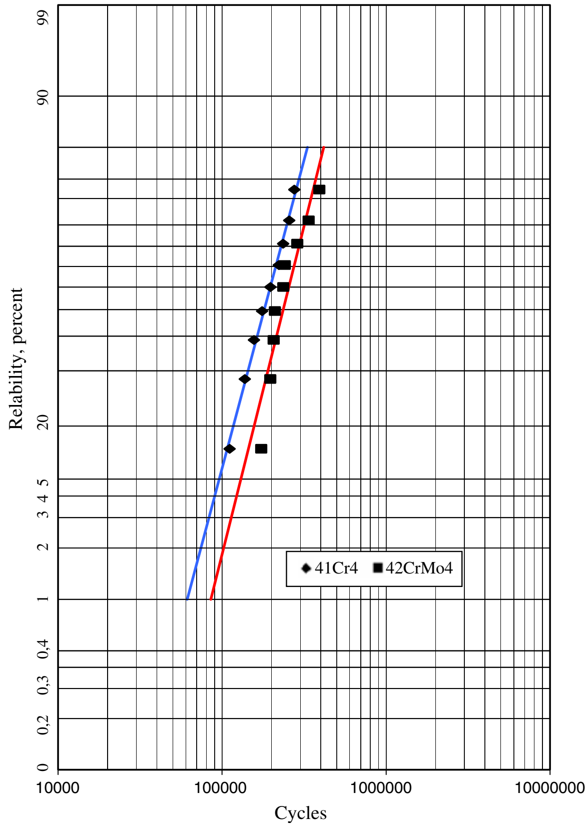

Fig. 9 Weibull plot of fatigue life

After tempering the 41Cr4 material at a lower temperature than that of 42CrMo4 material, it was possible to have the same hardness value. For example, 41 HRC value for 41Cr4 may be obtained by tempering at 450 °C. As mentioned earlier, these materials have been widely used for driving element materials. In practice, all the calculations made are usually based on yield points and hardness values. Stresses formed on the part must not go beyond the yield point. Otherwise, this part cannot function properly because of its permanent deformation above the yield point. Yield and hardness data indicate that it is possible to use 41Cr4 instead of 42CrMo4 material by just tempering at a lower temperature.

The fatigue life test was performed for both of the materials and repeated for nine times. 41Cr4 material for fatigue test had a 27.5 HRC after the tempering at 600 °C. It failed at different ranges from 111,234 to 275,623 cycles (Fig. 9). All the samples failed at the same location, which was the ball joint necked region. The necked region diameter was about 16.6 mm. There was a significant discrepancy between results. Therefore, it was expected that each sample might have different temperature distribution and different microstructure. The hardness of 42CrMo4 steel was also 27.5 HRC after the tempering at 650 °C and ball joint necked region diameter was 16.6 mm. The failure cycles for nine ball joint test samples ranged from 173,424 to 391,954. Same discrepancy was also detected and all the samples were fractured at ball joint necked region. The comparison of both materials is shown in Fig. 9. This shows that 42CrMo4 materials have better life and reliability.

4. Conclusion

In this study, a comparison study was made for automotive front driving elements materials: 41Cr4 and 42CrMo4 low-alloy steels. It is concluded that tempering 41Cr4 at lower temperature than 42CrMo4 makes possible to get almost same yield and hardness data. This eliminates to use different materials and also reduces manufacturing cost of automotive driving parts. Although 41Cr4 is more preferable from the manufacturing cost point of view, the fatigue test results indicate that 42CrMo4 is preferable in terms of fatigue life.

Acknowledgment

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