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EFFECT OF THE DEFORMATION OF THE COLD DRAWING ON FATIGUE LIFE OF THE SAE 1010 STEEL

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Abstract

In this study, it was examined the effect of the deformation provided by the cold drawing on mechanical properties of the Ç1020 steel particularly on fatigue life. Process parameters were kept constant for all specimens in cold drawing process. Deformation amount was 15 %. Hot rolled and cold drawn specimens were subjected to tensile, fatigue and hardness tests as well as microstructure examination. Results showed that grains of deformation provided with cold drawing elongated to the deformation direction and reduced. In addition, deformation of cold drawing increased considerably tensile and fatigue strengths and hardness values. Its effect was observed on yield strength at most.

Key words: Cold drawing, Microstructure, Tensile strength, Fatigue life

1. Introduction

Cold drawn steel rods are used in a wide portfolio of industries. In spite of some disadvantages of cold drawing, it generally provides some advantages such as high quality surface, high strength, measurement sensitivity, and the final measure. It is seen in overseas applications that there are very complex applications of shapes, sizes, and materials and cold drawing process can be used in a wide area. However, cold-drawing process in our country is limited to only rail drawing, conventional machine production steel rods and wire drawing profiles. Putting forward the developments provided as a result of cold drawing through experimental studies and determining its limits are very important for industrial applications, and it could have common benefits.

Fatigue behavior of materials is regarded as a very complex event. The reason for this is due to its being connected to many different factors. The most important ones of these factors can be listed as surface tensile stresses, surface roughness and surface fractures. Minimizing or eliminating these factors through various operations constitutes the basis of the studies. Surface hardening processes and cold drawing are generally considered to be among the processes that increase the fatigue strength. However, the type of material can cause different effects on fatigue behavior with the characteristics of cold-drawing process itself (amount of deformation, pass number, surface quality provided, etc.) [1,2].

Up to present, a lot of studies have been conducted on cold drawing and fatigue. It was stated in these studies that besides increasing the strength of metals, cold drawing process also increases their fatigue resistance. For example Tarakçılar [2] applied cold drawing process to Ç1020 steel at various proportions, measured and analyzed the formed stresses. Varol and Bedir [3] examined the importance and effect of residual stress on fatigue limit. They concluded that the effect of tensile residual stresses on fatigue strength was harmful, whereas the effect of compression residual stresses on fatigue strength was beneficial. Can, Kandemir and O. Ası [4] also concluded that cold forming hardening generally improved the fatigue strength. One of the most interesting results of these studies was reported by Van Ackek et al [6]. They determined that tensile strength of cementite lamellas after cold drawing was found to increase up to 2000 MPa. H. Lowak and O. Buxbaum

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[8] concluded that depending on load amount, load type, and material, residual stresses formed through cold drawing process affected fatigue strength positively. J. Toribio and E. Ovejero [9] examined the effect of cold drawing continuously applied to pearlitic steels on microstructure. They determined that pearlite lamellas get extensionally thin parallel to the tensile direction. Chin, G. Y.[10] studied changes occurred in the microstructure of 4Mo-79Ni-17Fe material to which cold deformation was applied.

The Ç1010 steel used in this study is one of the most widely used commercial steels which are cold drawn. Economic and technological conditions are forcing it. In available literature, mechanical results provided through cold drawing process particularly for Ç1010 steel have not been evaluated. It was aimed in this study to obtain information to be benefited in industrial areas by determining the effects of cold drawing process on SAE1010 fatigue and other mechanical properties, based on its importance.

2. Experimental studies

2.1 Material

The chemical composition of commercial SAE 1010 steel used in experimental studies is given in Table 1. This material was provided as hot rolled and wrapped as a coil 7 mm in diameter.

Table 1. Chemical analysis of SAE 1010 steel (weight %)

C	Mn	Si	P(max)	S(max)
0,12	0,55	0,12	0,026	0,045

2.2 Cold drawing

The preparation stages of cold drawn specimens were conducted in three stages such as oxide removal, surface cleaning and lubrication. The Ç1010 steel produced by hot drawing was subjected to oxide removal process performed with sandblasting. The balls used in sandblasting process left traces on the surface of the material and these traces enabled the drawing lubricant to attach on the surface. The second stage is surface cleaning process. At this stage, plating is performed according to the type of material and cold drawing process. The hot drawn material whose surface was cleaned with sand-blasting was lime plated in order not to re-oxidize. In lime plating, the coil was submerged into lime water bath at 90 ºC and the process was continued until the material temperature reached at the bath temperature for the plating to be fine. The circulation of the lime bath made the plating be more homogenous. The last stage is lubrication process. A mineral lubricant was used in the process. In this way, it was aimed to obtain process convenience and delicate surface by minimizing the friction during cold drawing process. The surface was not required to be subjected to any cleaning process after the cold drawing process. The thick lubricated layer on this surface prevented the material from re-oxidizing.

The Ç1010 coil produced by hot drawing in 7 mm diameter was gradually reduced through cold drawing to 6, 5 mm (Figure 1) in the first step and to 6 mm in the second step. While the preparation stages to cold drawing were applied in the first step, only lubrication was performed in the second step. A total 30 % cold deformation (reduction) occurred in two steps in the Ç1010 steel reduced from 7 mm diameter to 6 mm diameter.

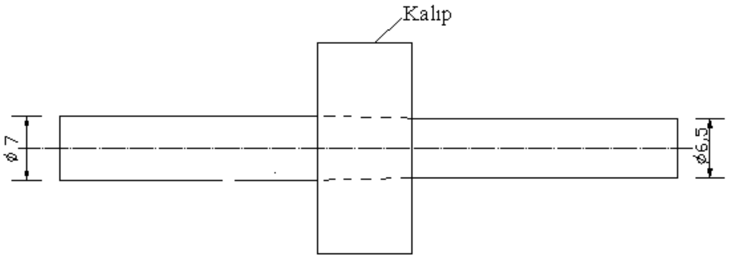


Figure 1. Initial step cold drawing of Ç1010 steel

2.3 Microstructure analysis

In order to analyze the microstructure, specimens were taken at two different directions from hot rolled and cold drawn specimens and they were prepared with standard metallographic method. Optical analyses were conducted in an optical microscope.

2.4 Hardness test

The hardness test was conducted with the Instron Wolpart brand test device with the Vickers method by applying a 1 kg load in order to form hardness variation profiles occurring on the surface and in the center of the hot and cold drawn materials.

2.5 Tensile test

The tensile test specimens prepared according to EN 10000-2 standard are shown in Figure 2 and Figure 3. In order to preserve the deformation effect, the cold drawn specimens were not exposed to any machining. The tests were conducted with their cold drawing states. Six tensile tests were conducted for each group of specimens.

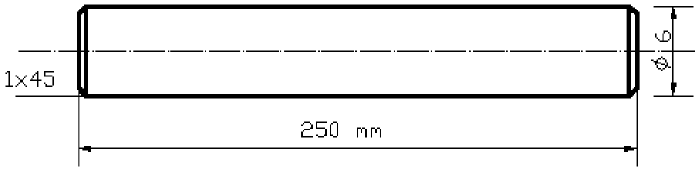


Figure 2. The tensile specimen of the cold drawn material

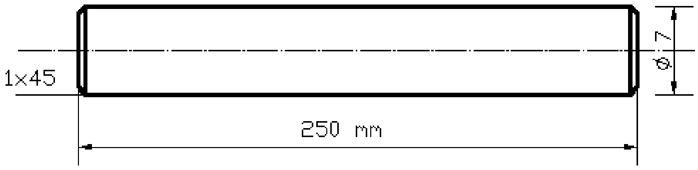


Figure 3. The tensile specimen of the hot drawn material

2.6 Fatigue test

Fatigue tests were conducted at room temperature through Free-Ended Beam Testing Apparatus. Six specimens were used for each point in the tests. While preparing specimens from cold drawn materials, specimens after cold drawing process were directly tested (Figure 4) instead of standard specimens. As in the tensile test, paying special attention to not processing on the surfaces of the cold drawing fatigue test specimens, the compression residual stresses on the surface were preserved. On the other hand, in hot drawn materials, the specimens were prepared according to the TSE 1487 (Figure 5). The stress values occurring in fatigue were approximated to proportional loading, considering the specimen areas.

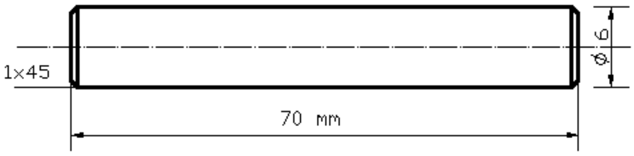


Figure 4. Fatigue test specimen for cold drawn serial

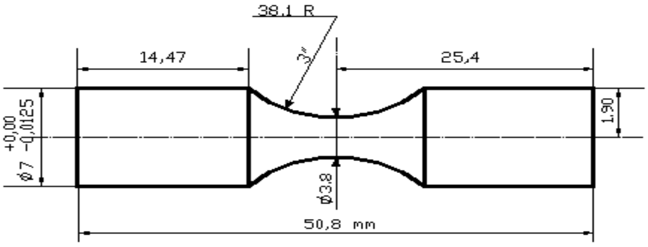
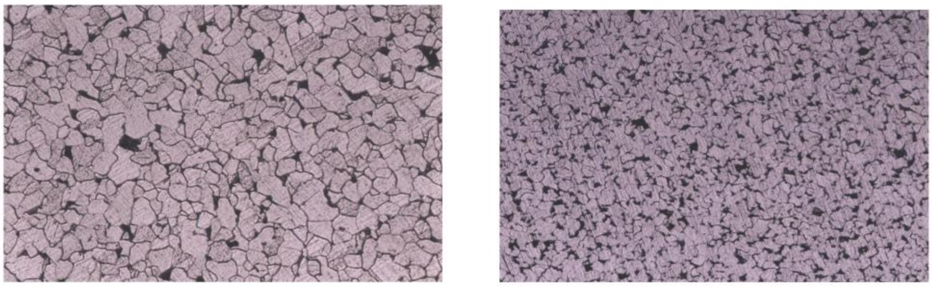


Figure 5. Fatigue test specimen for hot rolled serial

3. Test results and discussions

3.1 Microstructure

Microstructure of the hot rolled specimen of the SAE 1010 steel in perpendicular to the roll direction is seen in Figure 6 a, and microstructure of the cold drawn specimen in perpendicular to the tensile direction is seen in Figure 6 b.



a) Hot rolled b) Cold drawn (at 15% proportion)

Figure 6. Microstructures of the SAE 1010 steel specimens in perpendicular to the deformation direction×100

In Figure 6, the dark areas seen in microstructure photograph of the Ç1010 steel are pearlite grains, whereas the light colored areas are ferrite grains. Relatively smaller grains than the coaxial and hot drawn specimen grain structure are seen in microstructure photograph of the cold drawn specimens in perpendicular to the tensile direction. The reason is the size reduction seen in the microstructure of the grains (Figure 6.b) in perpendicular to the tensile direction because the grains of the materials elongated to the tensile direction through cold deformation.

The microstructure of the Ç1010 hot drawn material in parallel to the tensile direction is seen In Figure 7.a, whereas the microstructure of the Ç1010 cold drawn material in parallel to the tensile direction is seen In Figure 7.b. While coaxial and homogenous grains in parallel direction to the tensile in hot drawn material are seen in Figure 7.a, it is seen in Figure 7.b that grains elongated in parallel direction to tensile in cold drawn material. Because of the cold deformation occurred in Ç1010 steel, the homogeneity in grains was destructed, and the grains were elongated in the direction of tensile. When the microstructures of the hot rolled and cold drawn material are compared, elongated grains are seen in the cold drawn material due to the compressive stress caused by the mold in a parallel direction to the tensile direction (Figure 3.2. b), whereas generally an coaxial and homogenous grain structure in parallel direction to the tensile direction is seen in the hot rolled specimen (Figure 7.a). On the other hand, while small and coaxial grains in perpendicular direction to cold drawing direction are seen in the cold drawn specimen (Figure 7. b.), a big and homogenous grain microstructure in the perpendicular direction to the tensile direction is seen in the hot rolled material (Figure 7.a). From here, it is seen that the grains elongated in the cold drawing direction because of the cold deformation effect and when the same material was examined in perpendicular, it was observed that there was a contraction and as a result a reduction in grain cross-sections due to the elongation. These results are consistent with the general information in such a way that while the soft phases elongated in the deformation direction, their cross sections narrowed. On the other hand, the hard structures tended towards the deformation direction. However, the ferrite in pearlite discussed as the hard structure here can be accepted as auxiliary in the pearlite’s tending towards deformation direction without refracting. The previous researchers have also reported similar results [9, 10, 11]. J. Toribio and E. Ovejero [9] examined the effect of cold drawing continuously applied to pearlitic steels on microstructure and they concluded that pearlite lamellas elongated and become thinner in parallel to the tensile direction. The most important reason of this thinning is most probably the soft ferrite. Otherwise, cementite in pearlite, which does not have deformation capability, could have been expected to be fractured.

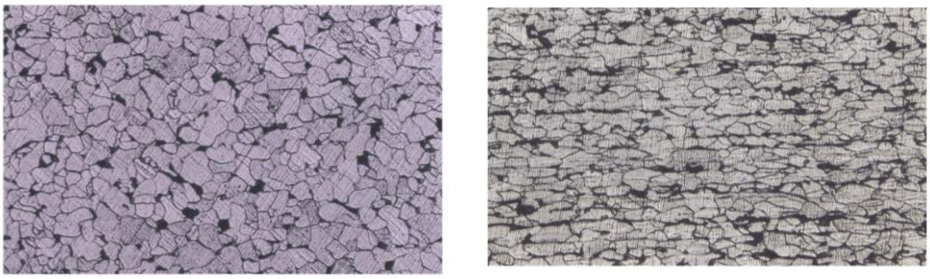

a) Hot rolled b) Cold drawn (at 15 % proportion)

Figure 7. Microstructures of the SAE 1010 steel specimens in parallel to the deformation direction x 100

3.2 Hardness

Vickers hardness results of the hot rolled and cold drawn material and their conversion to the other types of hardness are given in Table 2. A hardness increase at 45 % on the surface and 37 % in the center was observed in the SAE 1010 steel with a 15 % deformation. The hardness value in the hot rolled material was approximately 140 HV. On the other hand, while the hardness value of the cold drawn material was 202 HV in places near the surface, the center was observed to have 192 HV hardness value. The reason is that the cold deformation occurred on the surface was more than the one in the center. The previous researchers have also reported similar results [9-12]. However, the hardness variations can be changed depending on the type of material used and deformation processes and amounts.

Table 2. Hardness results

Specimen Groups	Vickers Hardness Value (1 kg)		Brinell Hardness Value (3000 kg)		Rocwell Hardness Value HR_B (100 kg)	
	Surface	Center	Surface	Center	Surface	Center
Hot-rolled	140	140	140	140	76	76
Cold Drawn	202	192	202	192	93	90

3.3 Tensile test

The results of tensile test applied to the hot-rolled and cold drawn specimen groups are given in Table 3. As it is seen in Table 3, the cold drawing process also increased the strength considerably as in hardness. While the yield strength was 34 kg/mm^2 in the hot rolling, it was 61 kg/mm^2 as a result of the cold drawing. While the tensile strength was 45 kg/mm^2, it increased to 65 kg/mm^2 as a result of the cold drawing. The yield strength increased as 82 % with 15 % deformation, whereas an approximately 45% increase was observed in tensile strength. However, although the ductility of the hot rolled material was 19 %, it decreased to 6 % due to strain hardening in the cold drawn material (Table 3). The previous researchers have reported similar results [6,12]. Toribio and J., Lancha, A.M. [12] observed in their material that the yield strength increased from 725 MPa to 1500 MPa, the tensile strength increased from 1300 MPa to 1830 MPa, and the % elongation decreased from 8 to 5,8. Generally speaking, it is observed that the cold drawing process increased the yield strength approximately once and the tensile strength at a proportion of 50 %. These results can be interpreted as cold deformation is more effective on yield strength [13].

From the yield and tensile strength values and elongation values in Table 3, the cold drawing process is seen to have decreased thickness at a significant amount. As the previous researchers have reported, this state is a result of strain hardening due to deformation [6,12,13].

Table 3. Tensile test results

Specimen Group	Yield strength (kg/mm^2)	Tensile strength (kg/mm^2)	Rupture strength (kg/mm^2)	% Elongation
Hot-rolled	34	45	30	19
Cold Drawn	61	65	49	6

3.4 Fatigue test

S-N graph of the hot rolled and cold drawn specimens is given in Figure 8. While the material fractured in hot rolled material at 30,15 kg/mm^2 stress and at approximately 101820 cycles (Figure 8), it fractured at approximately the same stress (30,6 kg/mm^2) at approximately 925288 cycles in the cold drawn material (Figure 8). It increased from approximately 101820 cycles to approximately 925288 cycles as a result of the cold drawing process.

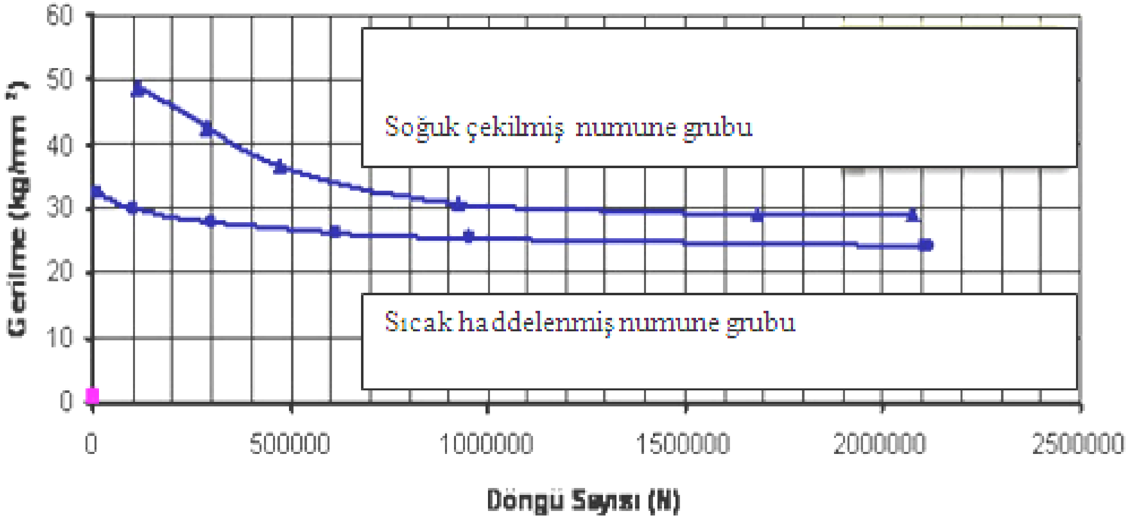


Figure 8. S-N graph of the hot rolled and cold drawn material

As seen in Figure 8, while the fatigue limit of the hot rolled material was 25,5 kg/mm^2 , it eventuated as 30,1 kg/mm^2 in the cold drawn material. The fatigue limit was seen to increase approximately 5 kg/mm^2 in the cold drawn material. It was also observed that the increases in the tensile and hardness tests continued parallelly in fatigue. There was not any fatigue fracture after 10^6 cycles in both materials.

These experimental results reveal that cold drawing process improves the fatigue strength of the Ç1010 steel. As it has been reported by the previous researchers, the causes of this can be listed as thinning of grain structure and increase in strength and hardness along with strain hardening [9-12]. Most probably, in axial fatigue conditions, tensile and compressive stresses formed perpendicularly to the cross-section with a convenient combination in the stress transfer of ferrite soft and resistant cementite lamellas in the banded structure in the cold drawn structure enable the continuation of the strain hardening along with the increase of fatigue strength. Additionally, particularly the compressive stresses formed on the surface can also be interpreted to correspond to the repeated tensile stresses occurred during fatigue and increase fatigue cycle number and fatigue limit. There are differences in evaluating the residual stress formation during cold drawing among the previous studies. The reason of these differences could be resulting from the differences of the material type used and the deformation amounts applied. As it is stated above, the development of fatigue strength after cold drawing along with other factors was evaluated in this study that compressive stresses occurred on the surface. In this regard, R. Varol and F. Bedir [3] determined that compressive stresses occurred due to fatigue on the surface were beneficial, but tensile stresses were harmful. The results of the studies conducted by A. Ç. Can, K. Kandemir and O. Ası [4], İmrak, C. E. and Fetvacı, C. [14], and A.

R. Tarakçılar [2] are consistent with the results of Varol and Bedir [3].

Cold shaping hardening processes are generally assumed to develop fatigue strength. The nuance to be considered here could be as such: Yes compressive stresses are preferred for fatigue strength on the surface. However, the amount of cold drawing and the material type have a significant effect on cold drawing process and the stress type and the force to occur on the surface. There are also some evaluations in the way that generally in shot-peen conditions, tensile stresses occur in processes such as compression on the surface and cold drawing in which deformation amount is much [1].

4. Conclusion

Cold drawn materials are often used both in our country and abroad in many industrial applications such as automobiles, agricultural machinery, electrical household appliances, nuts, bolts, shafts, pistons, and gears because the cold drawn materials are produced ready for use. Generally no additional process is performed to a cold drawn material. The smoothness of the surface of the cold drawn material and formation of compressive stress on the surface have increased mechanical properties. As a result;

- While the grains elongated in the tensile direction along almost the whole cross-section of the microstructure with the cold drawing process, the grain cross-section perpendicular to the tensile direction decreased relatively.
- While the tensile strength of the material increased approximately 36 % through the cold drawing process, the yield strength increased at 82 % proportion. On the other hand, while the ductility decreased as 68%, the thickness also decreased through the cold drawing process.
- While the hardness of the material increased 45% on the surface, it decreased at 37 % proportion in the center through the cold drawing process.
- The cold drawing process (15%) increased the fatigue strength of the Ç1010 steel at 22 % proportion.

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