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Research Article

The Effect of Hot Rolling Parameters on Mechanical Properties of Steel

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Abstract

The production of steel materials holds a significant place worldwide. Due to their mechanical strength and high resistance to friction, steel materials have been frequently preferred in many industries in recent years. This study investigates the effects of the chemical composition of steel materials, rolling speed, and the water-cooling system applied during rolling on the material's mechanical properties (yield strength, tensile strength, impact toughness). The mechanical behaviours of three different grades of materials were examined. According to the obtained results, a direct effect of manganese, vanadium, and aluminum elements on mechanical properties was observed. An increase in the amount of manganese in the steel material, and the combined use of vanadium and aluminum elements, led to an increase in yield and tensile strength. Increasing the amounts of vanadium and aluminum improved the material's notch toughness. The effects of two other important parameters, rolling speed and the water-cooling pumps in the rolling system, were examined. As a result, it was determined that reducing the rolling speed improves the mechanical properties of the material, and increasing the number of water-cooling pumps also improves the mechanical properties by allowing the material to absorb more water.

Key Words

Mechanical properties, rolling speed, water cooling, chemical analysis

Sıcak Haddeleme Parametrelerinin Çeliğin Mekanik Özelliklerine Etkisi

Öz

Çelik malzemelerin üretimi dünyada önemli bir yere sahiptir. Çelik malzemelerin mekanik direnci ve sürtünmeye karşı yüksek koruması nedeniyle son yıllarda birçok sektörde çelik malzemeler sıklıkla tercih edilmiştir. Bu çalışmada çelik malzemelerin kimyasal bileşiminin, haddeleme hızının ve haddeleme sırasında uygulanan su soğutma sisteminin malzemenin mekanik özelliklerine (akma mukavemeti, çekme mukavemeti, darbe tokluğu) etkisi araştırılmıştır. Üç farklı kalitedeki malzemenin mekanik davranışları incelenmiştir. Elde edilen sonuçlara göre mangan, vanadyum ve alüminyum elementlerinin mekanik özelliklere doğrudan etkisi gözlemlenmiştir. Çelik malzemedeki mangan miktarının artması, vanadyum ve alüminyum elementlerinin bir arada kullanılması malzemenin akma ve çekme mukavemetinin artmasına neden olmuştur. Vanadyum ve alüminyum miktarlarının arttırılması malzemenin çentik tokluğunu arttırmıştır. Ayrıca diğer iki önemli parametrenin, haddeleme hızının ve haddeleme sistemindeki su soğutma pompalarının etkileri incelenmiştir. Sonuç olarak, haddeleme hızının azaltılmasının malzemenin mekanik özelliklerini iyileştirdiği, su soğutma pompalarının arttırılmasının da malzemenin daha fazla su almasına olanak sağladığı için mekanik özellikleri iyileştirdiği belirlenmiştir.

Anahtar Kelimeler

Mekanik özellikler, hadde hızı, su soğutma, kimyasal analiz

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1.Introduction

The production of steel materials has an important place in our country and the world. The durability of steel and its use in the construction sector are among the significant reasons for its preference. Steel structures are widely used in buildings worldwide because of their good seismic performance and high construction efficiency (Jiang et al, 2018). In the early days of its use, the predominant structural steel types used for building construction were carbon steel or mild steel, which have nominal yield strength values of approximately 200–300 MPa, like ASTM A36 steel under the American standard, S235 and S275 under the European standard (Yu et al, 2019). In Europe, the steels with a nominal yield stress equal to or above 460 MPa are called high-strength steel based on the implication of the current European Standard. High-strength steel offers higher performance in tensile stress, yield stress, bending, weldability, and corrosion resistance when compared with steel (Qiang et al, 2012). In addition, the mechanical resistance and friction protection of steel materials are quite high. Steel materials are used in kitchen utensils, railway projects, the automotive industry, bridges, space vehicles, machinery, and external construction systems in many fields. Steel is an alloy of iron (Fe) and carbon (C), produced in two ways by recycling from ore or scrap. The products included in this study are low-alloy steel products and contain 0.1-0.3% carbon. The chemical composition and internal structure of the material determine the different properties of steel. Alloying elements can be added to the steel in different proportions, and its internal structure is controlled by various processes, steel products with different properties are obtained according to the purpose of use. Manganese (Mn), Phosphorus (P), Sulfur (S), and Silicon (Si) are elements present in steel during the production process. Other elements (Cr, Ni, etc.) are also added to steel in specific proportions. Since these materials will be produced in different profiles, each one must undergo a different shaping process. To carry out this shaping process in steel materials, a rolling process is required. Steel rolling is a plastic deformation process where steel is passed between rotating rolls, subjecting it to pressure forces. Rolling is a forming process that provides a wide range of uses, providing final product control and high production. The rolling method is based on loading the material with pressure forces of suitable size (Bartın, 2023). The first stage of this process involves heating the material in the hot deformation zone to increase its workability and reduce the flow stress of the deforming metal (Serajzadeh,2014). During rolling, a change in the dimensions of the material occurs with deformation. Certainly, with the change in this sizing process, changes occur in the internal structure of the material. During hot rolling, the microstructure and mechanical properties of the material change in conjunction with its thermomechanical state, which is determined by composition, reduction percentage, strip thickness, strip speed, and heat transfer (Samarasekera,2001). Although these changes affect the mechanical properties, they are linked to the chemical components that make up the quality of the material. There are two types of rolling processes, hot and cold rolling. In the continuation of the research, the impact of the chemical composition of steel, rolling speed, and water-cooling pumps on the mechanical properties of the material will be investigated (Aydın, 2017). Rolling is the name of the process of shaping the material by passing the steel materials of different profiles and sizes between the cylinders rotating in opposite directions and at certain speeds. In this applied process, while elongation of the steel product is desired, transverse expansion of the material is not desired. The rolling process differs according to the techniques and properties used. The rolling process is also a plastic-forming method. Plastic deformation is based on the plastic property of objects, that is their ability to permanently change their shape. Most of the plastic shaping is done by rolling. The first purpose of the rolling method is to compress the rolled material, making it denser. In this way, bunker and similar gaps are eliminated or reduced. At the same time, slag deposits in the material are expelled. The second purpose is to make the material into a smaller cross-section. Thus, the raw blocks are cast in the steel mill; It is passed through the rolls and formed into shaped sections with the desired internal and external smoothness and in forms that can be used in the technique. It is based on the loading of the steel material with appropriately large compressive forces. During rolling, the dimensions of the steel material are changed by deformation. In the meantime, changes in the internal structure and physical properties of the applied steel material cause changes in the mechanical properties of the applied steel material by changing the dimensions of the material. Steel is an alloy of iron and carbon. The deformation process applied to alloys like steel is called rolling. In all these processes, rolled ingots require a certain annealing step. Steel bloom can be annealed at temperatures ranging from 1100°C to 1250°C. The annealed steel ingots are thinned by the pressing force applied by the rotating roller systems. Hot rolling is considered the primary process applied to a steel material. In terms of cost, the hot rolling process requires much less processing, and therefore, it is more cost-effective. To eliminate the internal stresses that will occur after hot rolling, the material is subjected to a cooling process with water and left on the platform. Rolling the ingots to the desired material thickness requires quite a large amount of deformation. The hot rolling process is required for the realization of this amount of deformation. Strain-hardening makes deformation more difficult, but it also causes the steel material to break and tear to its internal structure. Here, the hot rolling process helps to eliminate the difficulties that occur due to the problems of this structure of steel materials. In the hot rolling process, the material can be deformed at very low loads, which means less energy consumption. There are two purposes for heating raw blocks or semi-finished products before rolling. Firstly, it must provide plasticity to the material, thereby reducing its resistance to shaping. The second is the correction of the inner texture of the steel. To carry out these processes, the materials are heated in annealing furnaces to the required temperature and kept at this temperature for a certain time. The temperature of the ingot at the exit of the furnace is around 1150 ºC. Two events occur in the high-temperature area. Scale formation and carbon burning. Although these formations are not desired, they cannot be prevented. The formation of scale causes loss of material. The material properties deteriorate with the combustion of carbon. Scale causes approximately 1.5-4% material loss. The formation of scale is an undesirable situation. In this study, the effect of the chemical composition of steel materials, rolling speed, and the water-cooling system during rolling on the mechanical properties of the material (yield strength, tensile strength, impact toughness) was investigated.

2.Materials and Methods

2.1 Parameters

This study investigated three different parameters affecting the mechanical properties of hot-rolled products. These are as follows:

- Effects of alloying elements in steel
- Water-cooling pressure
- Rolling speed

During rolling, chemical analysis results were checked for three different grades, the rolling speed value in production was altered, the water pressure value was adjusted during rolling, and how all these values changed the mechanical properties of the products was examined. The rolling speed value was increased every half an hour to observe whether it decreased the mechanical properties, and it was investigated whether the water-cooling pressure, increased with the help of pumps, also changed the mechanical properties. The change in values is shown in Table 1 and Table 2.

Table 1 Rolling speed values in the production line

Production time (minute)	$V_{Rolling}$ (m/s)
30	13,4
60	15,2
90	18,7

Table 2 Water-cooling pressure in production

Production order	Number of water nozzles	Water pressure (Bar)
First Production	3	1,2
Second Production	5	2,1

2.2 Chemical analysis

The chemical analyses were made with a spectrometer The basic principle of the device is based on optical emission. Tests were carried out on pieces of different sizes taken from the production. For proper sample preparation, the sample surface should be well grinded, the surface should be flat so that the surface does not burn while grinding and the surface of the grinder does not miss the light. Chemical analyses have been tested for three different grades. In this study, three different chemical qualities were examined for the prepared 20x5 flat bar using a spectrometer. Considering the chemical analysis, the sample was first ground without burning or damaging the surface.

2.3. Tensile strength test

The tensile strength test was carried out with a 50-ton tensile. It was made by preparing 20x5 flat iron from large sizes. The prepared sample must be free of burrs. In addition, the extracted samples should be properly sized according to the standard and well-shaved from the CNC machine. Tensile sample is shown in Figure 1.

Figure 1. Samples prepared for the tensile test

The amount of flow, shrinkage, and elongation was measured according to quality and different chemical contents. A plastic deformation zone was observed. Three different grades were made separately. First, the L_0 length of the sample was calculated, then the L_1 length was measured, and the amount of elongation was measured. L_0 length was found with the formula cross-sectional area x5.65. The sample was prepared according to EN 10025 standard (Türk Standartları Enstitüsü, 2004). The sample was prepared as a 20x5 flat sheet for the tensile test. The L_0 length was calculated with the formula (cross-sectional area x 5.65). Then, the L_0 length was calculated. Then, the L_1 length was measured manually and the amount of elongation in the sample was calculated.

2.4 Impact test
The impact test was used in the notching device using 300 J. Samples in the size of 55x10x10 were prepared on CNC benches. The sample is shown in Figure 2.

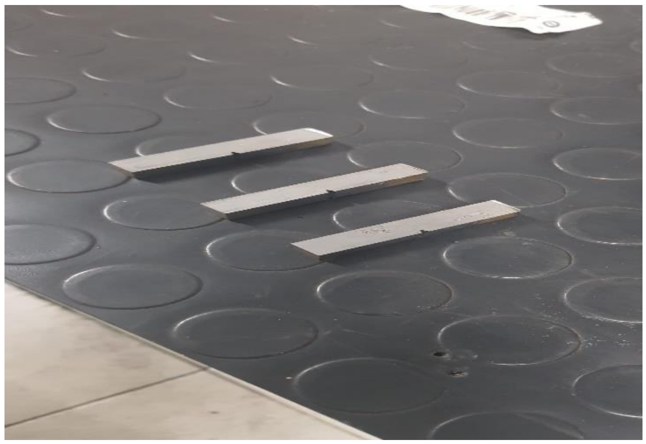

Figure 2. Sample prepared for the impact test

The importance of each millimeter was considered during the preparation of the experiment. In addition, values such as notch depth and temperature were checked. Three different grades were tried, and different temperatures were adjusted according to different grades. The samples were prepared in different conditions, -20 ºC, and room temperature. In addition, the direction of the notch was checked within the standard. According to the EN 10025 standard, a 55x10x10 thick sample was processed and removed on a CNC machine. Then, a notch was made in the middle of the neck. S275 JR quality and S355 JR quality were processed at room temperature, and S355 J2 quality was tested at -20 ºC.

3. Results and Discussion

3.1. Chemical analysis results
According to the results of the chemical tests conducted, it was observed that the quality class of steel changed when the manganese element increased from 0.65-1%. Similarly, it was determined that the quality class became more specialized when the aluminum and vanadium elements transitioned from 0.002% to the range of 0.025-0.029%. It was also noted that the material could produce slag when the copper element exceeded 30%. As shown in Table 3, the carbon values were the same in all samples, but manganese, aluminum, and vanadium differed.

Table 3 Percentage elements in steel products

Quality	C	Si	Mn	P	S	Cr	Ni	Cu	Al	V
S275 JR	0,170	0,240	0,650	0,021	0,016	0,120	0,016	0,300	0,001	0,002
S355 JR	0,170	0,190	1,310	0,021	0,018	0,092	0,082	0,280	0,002	0,003
S355 J2	0,170	0,200	1,220	0,010	0,011	0,090	0,089	0,270	0,025	0,029

Other elements were observed to be close to each other. The values of other chemical elements were not considered as differentiating factors since they were close to each other.

3.2. Tensile strength test results
The results of the tensile test were also examined as another important test. The test results for S275 JR, S355 JR, and S355 J2 have been shown in Fig. 3, Fig. 4, Fig. 5 and Table 4.

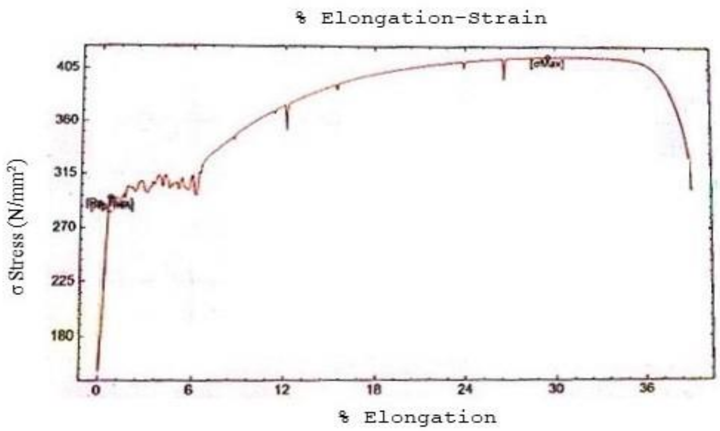

Figure 3. S275 JR tensile test

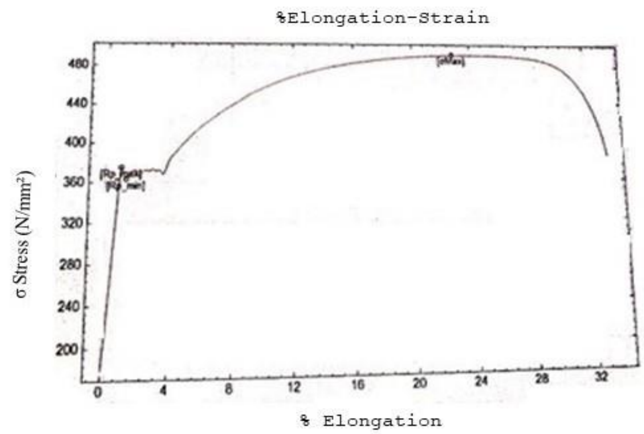

Figure 4. S355 JR tensile test

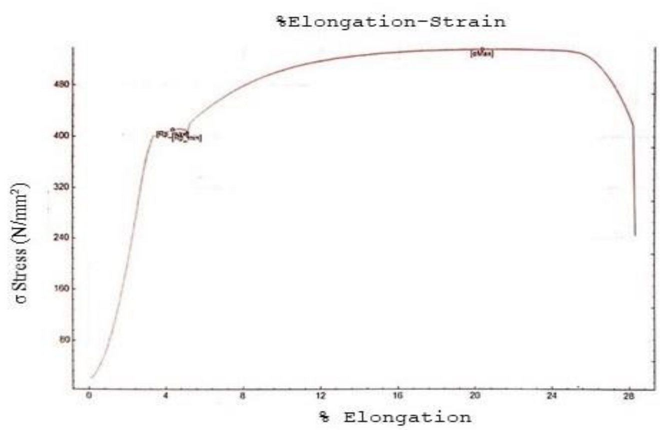

Figure 5. S355 J2 tensile test

Table 4 Tensile test results

Quality	**Yield Value** (N/mm^2)	**Tensile Value** (N/mm^2)	**Elongation** %
S275 JR	293.50	415.12	39.10
S355 JR	368.20	492.67	33.40
S355 J2	403.96	537.35	28.30

A tensile test was carried out for three different samples of S275 JR quality, S355 JR quality, and S355J2 quality. Broken tensile test sample is shown in Figure 6.

Figure 6. A broken tensile test sample

It was observed that the yield strength and tensile value of the S355 J2 sample were higher than that of S355 JR. The values are shown in Table 4. It was observed that the yield strength and tensile strength values of the S355 JR grade are higher than those of the S275 JR grade. Additionally, it was noticed that the material with lower yield and tensile values exhibited a higher elongation.

3.3 Impact test

Finally, notch impact resistance was measured for three different grades. The broken notch sample is shown in Figure 7.

Figure 7. A broken impact test sample

Results for JR grades at room temperature were seen in Table 5, while results for S355 J2 grade were taken at -20 ºC (temperature values according to EN standards) or S275 JR, a value of 33 Joule, for S355 JR, a value of 44 Joule, and for S355 J2 grade, a value of 63 Joule was measured in Table 6.

Table 5 Impact test results for S275 JR and S355JR

Quality	**Impact energy (J) at 25 ºC**
S275 JR	33
S355 JR	44

Table 6 Impact test result for S355 J2 quality

Quality	**Impact energy (J) at -20 ºC**
S355 J2	63

When we combine the three test methods overall, the following observations were made at the end of the experiment: It was seen that the impact resistance of S355 JR quality was higher than the S275 JR quality sample, and the impact resistance of S355 J2 quality was higher than the S355 JR quality. It was observed that vanadium and aluminum elements, which enable the formation of different qualities, increase the impact resistance on hot-rolled steel. As a result of the analysis and experiments, it is seen that the manganese element increased the strength of the steel. The effect of the carbon element on the strength and hardness of steel was observed. However, a discriminator was not used in this test. And then vanadium increased the hardenability of steels to a certain extent and increased the tensile and yield strength. It was observed that it increased the yield strength and impact toughness of aluminum. The mechanical properties of steel at elevated temperatures can be influenced by various parameters, such as the manufacturing process, test methods, rolling speed, and the efficiency of water-cooling pumps (Li et al,2021). The effects of water-cooling pumps and rolling speed were examined during production. When the number of water-cooling pumps decreased, it was observed the flow and shrinkage values of the material decreased. In cases where the rolling speed was increased, there were some physical problems. However, mechanically, the material hardened less because of less water. As a result, its yield and tensile strength decreased.

4. Conclusions

In hot-rolled steel products, it has been observed that the yield strength, tensile value, strength, and hardenability of the steel increase due to the increase in the manganese element in the samples. It has been determined that aluminum and vanadium elements increase the toughness and impact value of steels when used in the range of 0.025-0.029%. The effect of rolling speed on the material's mechanical properties has been observed. When the rolling speed slowed down, the surface of the material was exposed to more water, therefore its mechanical properties increased, and its yield and tensile strength increased. The effect of water-cooling pumps on the mechanical properties of the material was examined. It has been determined that as the number of connected water pumps increases, the yield strength, tensile values , and hardness of the material increase.

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