Surface properties of the cut face obtained by different cutting methods from AISI 304 stainless steel materials

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AISI 304 stainless steel which is widely used almost in all industrial applications is accounted for approximately 50% of the world’s stainless steel production and consumption. Because of its aesthetic view in architectures, resistance against corrosion and chemicals, it became as the most preferred material. Today several methods for machining of AISI 304 stainless steel are available. Most of these methods result in loss of superior properties of the stainless steel material and makes it to act like other ordinary materials within the machined zones. In this study, specimens taken from the AISI 304 material are cut by the cutting methods which are commonly used in machining. The resulting surface properties of these specimens are compared with original materials with respect to different methods. Finally mechanical and metallurgical properties of the cut face obtained by each method are examined. The results show that cutting with abrasive water jet gives the most favorable result while oxygen cutting gives the worst.

Keywords: Cutting methods, Comparison of cutting methods, AISI 304 stainless steel material, Surface characteristic, Surface quality

With the developments in cutting technologies, surface properties obtained by pre-manufacturing and specifically final machining applications have high importance. Machining quality in the cutting methods, generally, is characterized by change in material properties, cut edge deformation, cut surface properties and cut channel geometry. Common use of many cutting processes introduces questions like “which cutting method is more efficient for a given material?” Within this context, main aim is to find the fastest, cheapest, top quality method yielding in the least deformation on the cut edge and its vicinity. In many cases, one or more of these criteria may be neglected.

Despite the ongoing evolution of cutting methods since more than a century, some application limitations and weaknesses makes it inevitable to search for new methods. There exist several limitations and weaknesses in application of new cutting methods, i.e., abrasive water jet (AWJ), laser beam cutting (LBC), plasma beam cutting (PBC), water shield plasma cutting (WSPC), and wire electrical discharge cutting (WEDC) that have been invented other than conventional methods like oxygen flame cutting (OFC), saw cutting (SC) and milling cutting (MC). It does not appear possible to avoid thoroughly these weaknesses. Having different machining principles and providing means for engineering design, these methods facilitates miniaturizing, using extra ordinary materials and flexible manufacturing techniques that have serious impact on today’s economy. The quality of cutting process done by any method can be determined by measuring some properties such as surface roughness, tolerance control, flatness and perpendicularity. These parameters must be taken into account while comparing cut faces obtained by different methods. With the developing technology, deficiencies like cutting quality, cutting precision, repeatability of process and time in conventional cutting methods are discovered. Therefore, new methods are researched continuously in order to get the fastest, most quality and least surface deformation with minimum cost. Several new methods were found and applied as the result of these researches. Among those, cutting methods based on jet flow (Fig. 1) which are becoming widely used day by day constitute as most preferred methods. In all of these methods based on jet flow AWJC, LBC, PBC and WEDC, the surfaces obtained are in parallel lines. However, when the surface is examined in micro level, micro properties of the surface differs from each other as the cutting mechanism is different in each method.

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The surface quality obtained by these methods based on jet flow, can be developed by increasing the power consumed per each unit of cutting length. More quality surface can be attained by increasing in the jet pressure and decreasing the lateral feed rate\(^4\sim8\). The quality zones of a surface obtained by cutting based on jet flow are given in Fig. 2.

Recent researches approved abrasive water jet cutting system (Fig. 3) to be one of the most efficient cutting methods. AWJC as a cutting system releasing no corrosion, no evident revolution, no chipping at the edges, no unwanted forces that can yield in deformation of material while cutting, no heat effect and hence never resulting in any problems such as structural deformation, tarnishing, distortion, melting, dripping and oxidation, can cut even most complex shapes at close tolerances and generating very clean surface properties\(^9\).

**Evaluation on Cutting Methods**

There are many methods to be used in cutting materials as sheets of specific thicknesses. These methods are compared by Hashish\(^10\) as shown in Fig. 4. A comparison is made by taking into account the power levels and typical metal removal ratios of different machining methods.

In his assessments performed according to the abrasive water jet, Hashish stresses that, as compared to the conventional methods, the energy distribution formed within the water jet which has the capacity to
cut with fairly low energy consumption, is too dense and a significant part of this energy is consumed by friction as in the cases of other single orifice jet beam cutting processes (LBC, PBC, WSPC). Jet of small diameter applied on the piece is able to cut in every direction while being perfectly directed and hence is able to create quite narrow cuts. Particularly, as there is no thermal effect on the cut material, it became more effective than other methods.

A comparison of abrasive water jet with other cutting methods is given in Table 1. From Table 1, it can be seen that abrasive water jet cutting method is the most efficient cutting method regardless to the material thickness and properties. However, there are disadvantages of abrasive water jet machining technology besides its many advantages. The most important ones are those the system and cutting parameters are related to many variables and as these parameters cannot be recognized accurately, continuous surface quality throughout the cut depth cannot be achieved. Surface roughness which increases related to the cut depth is inevitable as in cutting with laser beam, plasma beam and water shield plasma and oxygen flame.

There are many studies regarding comparison of AWJ with other methods (Fig. 5). When referred to these different results according to different materials came into picture. Powell et al., have made a research on comparison of laser and AWJ methods in economics point of view. In their studies, they focused on relative efficiency of both machining processes by discussing technical and commercial advantages and disadvantages of the two methods.
Ohlsson et al.\textsuperscript{16}, have studied the effects of pressure, abrasive flow rate and lateral speed on cut depth and surface properties of steel and gray cast iron in cutting with AWJ. Zeng et al.\textsuperscript{17}, aimed at providing a conclusion for users on which of the methods is more convenient for which type of applications by performing studies based on the quality and operational cost. They focused on comparison of cutting stainless steel, plain steel and aluminum of different thicknesses. In all these studies, it has been stated that abrasive water jet cutting gives the best results with respect to laser beam cutting and plasma beam cutting which are said to be competitors.

When a general evaluation of cutting methods is made, abrasive water jet comes out to be the most efficient method despite some deficiencies. Other than those superiorities shown in Figs 4 and 5 and Table 1, the advantage of this method is that it is a cold process. Consequently, no mechanical and thermal stresses are realized on the cut material. Therefore, there is no need for stress removal processes afterwards. All materials can cut without any heat generation. Hence, unwanted hardening, droplets on the surface, melt metal dross and poisonous gas formations are avoided. On the other hand, having, no negative effect on environment can be declared to be most important superiority of the method.

\section*{Experimental Procedure}

\subsection*{Materials}

In this study, specimens were taken from AISI 304 austenitic stainless steel (Austenite (\gamma) stabilizer) of thickness 20 mm as shown in Fig. 6 and are cut with different cutting methods. The dimensions of the prepared specimens are $a = 20$ mm and $b = 100$ mm. All specimens are cut by 4 times and 8 different measurement surfaces are obtained. Chemical composition of materials is given in Table 2 and cutting parameters of AWJ are given in Table 3.

\subsection*{Method}

Specimens were cut by eight methods of conventional ones (oxygen flame, hydraulic saw, milling) and contemporary ones (abrasive water jet, laser beam, plasma beam, water shield plasma (focusing), wire electrical discharge). Feed rate of the material is selected as 20 m/min for each cutting method (except wire WEDC). Cutting and cooling conditions are selected in accordance with the machine manufacturers’ recommendations with
Table 2—Chemical composition of stainless steel material; AISI 304 Austenite ($\gamma$) stabilizer 304

<table>
<thead>
<tr>
<th>V</th>
<th>Si</th>
<th>Mn</th>
<th>Mo</th>
<th>Cu</th>
<th>Cr</th>
<th>Ni</th>
<th>Fe</th>
<th>C</th>
<th>P</th>
<th>Nb</th>
<th>Co</th>
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<td>0.116</td>
<td>0.498</td>
<td>0.979</td>
<td>0.217</td>
<td>0.228</td>
<td>17.30</td>
<td>8.06</td>
<td>72.30</td>
<td>0.0476</td>
<td>0.0338</td>
<td>0.0210</td>
<td>0.147</td>
</tr>
</tbody>
</table>

Table 3—Cutting system and cutting parameters

**Abrasive Water Jet Cutting**

- Water consumption: $\approx 3.5$ l/min
- System temperature of water: $48^\circ$C
- Working pressure of the booster: 200 bar
- Outlet pressure of water from the pressure booster: 20 bar
- Water flow rate: 3 l/min
- Outlet velocity of water from the nozzle: 800 m/s
- Temperature at the instance of cutting: $\approx 55^\circ$C
- Current consumption during work: 380 V
- Amount of abrasive consumed: 250 g/min
- Abrasive used: GMA Garnet
- Abrasive hardness: 7.5 - 8 Mohs
- Abrasive water outlet diameter from the nozzle: 0.75 mm
- Slurry content: % 18
- Mixing tube diameter: 1.27 mm
- Nozzle length: 76.2 mm

**Laser Beam Cutting**

- Cutting rate (Lateral feed rate): 20 m/min
- Position rate: 140 m/min
- Laser power: 1550 W
- Main power supply: GW 0-100 %
- Pulse type: Mega pulse
- Pulse change frequency: 2000 Hz
- Pulse time: NP(T) 1500 µs, SP(t) 120 µs
- Mod type: Sürekli mod (CW)
- Focus distance: 7.5 mm
- Cutting gas: Nitrogen
- Cutting gas pressure: 1.2 bar
- Cooling temperature: TA=25ºC
- Oxygen: TA=25ºC

**Plasma Beam and Water Shield Plasma Cutting**

- Cutting rate (Lateral feed rate): 20 m/min
- Position rate: 140 m/min
- Laser power: 1550 W
- Main power supply: GW 0-100 %
- Pulse type: Mega pulse
- Pulse change frequency: 2000 Hz
- Pulse time: NP(T) 1500 µs, SP(t) 120 µs
- Mod type: Sürekli mod (CW)
- Focus distance: 7.5 mm
- Cutting gas: Nitrogen
- Cutting gas pressure: 1.2 bar
- Cooling temperature: TA=25ºC
- Oxygen: TA=25ºC

**Wire Electrical Discharge Cutting**

- Cutting rate (Lateral feed rate): 20 m/min
- Current for maximum cutting: 760 A
- Nozzle pressure: 10 bar
- Processing condition: C521
- Processing conditions and parameters:
Specimens cut are left in ambient temperatures for cooling. Surface properties (microstructure, hardness) obtained after cutting processes are compared with those of original materials. As the results of measurements taken, it was observed differentiations in metallurgical structure of the materials throughout cut faces and zones close to this face. Therefore, microstructures, cut face hardness and roughness were evaluated on these cut faces.

Hardness values were measured at ten points being randomly selected on the surfaces of specimens obtained from every method and mean value of surface hardness were determined by calculating arithmetic means of these values. Measurements were taken by “Instron Wolpert Testor” and “HV30” values were obtained. Hardness measurements were taken at the cut faces of the specimens of 20 mm thickness obtained by different methods over five linear gauges 1 mm apart from each other starting from the cut face and their arithmetic means were calculated. Hardness changes were observed with respect to the heat distribution over the material. Consequently, how different cutting methods affect hardness of materials on cut faces and to which depth from the cut faces these effects can be observed. In order to make a comparison, the original hardness values of specimens at the center were determined before cutting. 20 measurements were taken by Mitutoyo Surftest Analyzer 402 at 5 different cut depth selected by sampling on each cut face and minimum, mean and maximum roughness values were calculated for each cutting method by taking the arithmetic means of $R_a$, $R_z$, ve $R_{max}$ values obtained. It should not be forgotten that, increase in surface roughness values are observed in relation with increase in depth from the upper surface on the cut faces obtained by cutting methods based on jet flow rates. Therefore, 4 measurements were taken at points which were selected by sampling from each cut face quality zones shown in Fig. 2 and mean values for roughness are found by simply taking the arithmetic average of 20 measurements obtained.

Also, microstructure pictures were taken on each cut face and the conclusions were made by evaluating not only the pictures given here but every picture taken throughout the study. Microstructures of parent materials and cut edges of cut faces were displayed by magnifying at 280× using “PANASONIC WV-CP410 Model Type N334” microscope and personal computers. Alumina powder and diamond paste were used in polishing and then etching with a mixture of “5g CuCl$_2$ + 100 mL HCI + 100 mL ethanol + 100 mL distilled water” was applied until the structure can be detected. Cutting parameters were selected from those suggested for AISI 304 stainless steel sheets of 20 mm thickness by equipment manufacturers.

### Results and Discussion

#### Evaluation of structural changes generated by different cutting methods

In order to perform metallographic evaluations, and to determine structural deformation and changes picture of microstructure were taken from a zone that cannot be affected by the cutting process (Fig. 7) and cut edges (Fig. 8). By examining these microstructure pictures, microstructures of cut faces obtained by different cutting methods and zones close to these faces can be compared with original microstructures.

#### Cutting with hydraulic saw

It was observed that the structure was undergone excessive mechanical deformation and the grains were reoriented. Fractures and cracks were generated through ferrite grain boundaries, and structural

<table>
<thead>
<tr>
<th>Abrasive Water Jet Cutting</th>
<th>Abrasive Water Jet Cutting</th>
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</thead>
<tbody>
<tr>
<td>Operating pressure</td>
<td>20 bar</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Cooling capacity</td>
<td>4000 kcal/h</td>
</tr>
<tr>
<td>Receiver tank capacity</td>
<td>30 l</td>
</tr>
<tr>
<td>Nominal voltage</td>
<td>400 V</td>
</tr>
<tr>
<td>Average sound level</td>
<td>68 dB(A)</td>
</tr>
<tr>
<td>Cutting gas</td>
<td>Oxygen+Propane</td>
</tr>
<tr>
<td>Control system</td>
<td>Fine APT</td>
</tr>
</tbody>
</table>

Parameters for each cutting methods are selected in accordance with the machine manufacturers’ recommendations.
changes were detected related to deformation and heat. No excessive phase change can be realized despite deformation hardening.

Milling cutting
The structure was undergone mechanical deformation and excessive fracture, deep cracks and flaws were detected through ferrite grain boundaries. Structural defects can be observed due to deformation in the cutting zone and its vicinity. As compared with the structure obtained by hydraulic saw, the grains were more reoriented as deformation speed and quantity were more. Heat affect stayed more limited than structural deformation as milling cutting was performed under cooling liquid media.

Cutting with water shield plasma
Excessive heating and rapid cooling at the cutting zone yields in fine granular structure and makes unstable austenitic structure become clearly detected martensite at the cutting zone. An increase in hardness and hence brittleness at the cutting zone is unavoidable due to rapid heating and rapid cooling. Also, as ferritic structure was formed at the heat affected zone, resistance to corrosion is to be decreased. Although there is a twin structure at the cutting zone, excessive deformation occurred at the cut face. Beyond this zone, austenitic structure was detained due to the application of cooling water but the grain sizes were explicitly reduced.

Cutting with wire electrical discharge
Structural changes were realized relating to heat at the cutting zone and because of rapid cooling hardens the brittleness of the structure was observed to be increased. Besides, crack formations occurred, they were limited to the cutting zone and its close vicinity. Beyond this zone, austenitic structure was preserved. It is unavoidable to result in a decrease in corrosion resistance at the cutting zone and its close vicinity.

Cutting with oxygen flame
Needlelike (Widmannstatten) structure was formed due to excessive heating and rapid cooling. This structure spreads over a wide range. Deep cracks were formed at the cutting zone and its close vicinity and phase changes were occurred. Chrome-carbide precipitation was also observed at the cutting zone due to excessive heating. Besides, as higher temperatures is reached an increase in the risk of

Fig. 7— Micro structure of AISI 304 austenitic stainless steel material

A needlelike (Widmannstatten) structure was observed. This needlelike structure became thicker and a shift to austenitic structure was observed proceeding inwards as the affect of heat is decreased. Chrome-carbide precipitations occurred at the cutting zone and the vicinity. Besides, the grains became smaller and hence apparent structural deformation was evaluated unavoidable.
Fig. 8 — Micro structure pictures of cut edges (a) cutting with hydraulic saw, (b) milling cutting, (c) cutting with water shield plasma, (d) laser cutting, (e) plasma cutting, (f) cutting with abrasive water jet, (g) cutting with wire electro discharge and (h) cutting with oxygen flame.
formation of sigma phase become evident. It is an unavoidable result that corrosion resistance is to decrease significantly at the cutting zone and wider range.

Depending on the changes in microstructure of materials, when heat affected zone and the size of this zone are taken into account, structural changes occurred as the result of high temperatures and rapid cooling in some methods are of significant importance. Depending on the properties of cutting method, coarse granular structure in some methods and fine granular structure due to rapid cooling in some other methods are observed. Also depending on the properties of cutting methods, gas inclusions and tendency towards micro crack formation is observed in the structure. Main reason why no deformation in the microstructure occurs in the cutting zone is that high temperatures are not reached in cutting with AWJ. In all methods other than abrasive water jet cutting, when the microstructures are examined from the cut face towards inside, the deformed microstructure views are returned to the original microstructure of the material after certain depths based on the method used. The most and the second most unfavorable ones among those are oxygen flame cutting and plasma beam cutting methods respectively. The regaining of the original structure from the cut face towards inside in the shortest depth can be seen in cutting by saw and cutting by milling methods.

A comparison of roughness values of cut faces obtained by cutting of AISI 304 austenitic stainless steel material of 20 mm thickness with different methods are shown in Fig. 9. An analysis of this figure shows that when the roughness values obtained for each method are evaluated, it can be observed that the coarsest cut face is obtained by cutting with oxygen flame and the finest cut face is obtained by cutting with wire electrical discharge method.

A comparison of hardness values of cut faces obtained by cutting with different methods with original hardness values of materials is shown in Fig. 10. This figure implies decrease in quantity of hardness values differs for each cutting method depending on methods applied. As a result of this, it can be stated that, changes in the hardness values are different depending on the individual properties of cutting methods. This tendency verifies that every method causes a change in the hardness values depending on their effects on metallurgical properties of materials.

It is known that, in conventional methods, most of the energy consumed for metal removal is released as “heat”, some of the energy is converted to deformation and small amount of energy is converted to lost energy regarded as “elastic loss”. It is also known that; temperature reached caused by the energy which is converted to heat, if not controlled, would cause changes in metallurgical properties of work piece materials. This temperature rise is the main reason for the significant change in the metallurgical properties as it exceeds the re-crystallization temperature of the material. Cooling conditions applied during metal removal, also, affects the metallurgical properties of the materials. Therefore, this can be concluded as the main reason of the change in mechanical properties such as hardness. The basis of oxygen flame cutting which is one of the thermal cutting methods, lies upon the principles of reaching the melting temperature of the material and
transfer of the resulting melt metal from that zone. Bringing the material to those temperatures and cooling conditions afterwards yields in significant changes in metallurgical and mechanical properties of materials. In this study, the occurrence most significant changes with respect to both the metallurgical properties and the hardness which was observed during oxygen flame cutting is an expected result.

Regarding the contemporary methods, changes in metallurgical properties and hardness values depends on the principles of the methods. The basis of laser, plasma and wire electrical discharge methods depends on the principle of cutting the materials at melting temperatures as in the case of oxygen flame cutting. The main reason for different metallurgical properties and hardness values obtained by these methods is that energy and cooling conditions applied are different. The reason why hardness values obtained by conventional methods such as water shield plasma and wire electrical discharge methods are better than those obtained by laser and plasma methods, can be described as in line with the fact that former methods are performed under shielding liquid and thus the temperature is relatively controlled.

Among the cutting methods applied, when comparison is made based on changes in metallurgical properties and hardness values with respect to the original materials structure and hardness values, the best results were obtained by AWJ cutting methods. Hardness of the surfaces cut by AWJ lies very close to the values of the original material. This can be expressed to be in relation with abrasion mechanisms used in this method. It is known that the change in temperatures stays in a very limited range (approx. $\Delta t=75^\circ C$)\textsuperscript{19}. This also explains the absence of heat affected zone (HAZ) in AWJ cutting. Based on this feature, cutting with AWJ method becomes prominent as an effective method by not causing changes in the original structure and hence mechanical and metallurgical properties of the materials.

Table 4 shows how different cutting methods affects hardness changes of cut faces at which ratio (as % change) in this study. The least change is obtained by milling cutting and hydraulic saw cutting methods other than AWJ cutting method. This can be related to selection of cutting parameters for conventional methods so as to avoid temperatures higher than re-crystallization temperatures.

Depending on the cutting method parameters, depth of heat affected zone changes starting from the cut face. Depending on the change in metallurgical structure resulted by cutting method, hardness measurements, taken at points 1 mm apart from each other starting from the cut face extending towards the center of specimens, gives some information regarding the size of heat affected zone. The results of these measurements for AISI 304 austenitic stainless steel were shown Fig. 11.

The most impressive result concluded from these figures, is that there is no linear tendency in cutting with AWJ method and hence there is no heat affected zone (HAZ) in the material cut with this method. Cutting with AWJ method comes into picture as a method that can perform cutting by not yielding in any change in metallurgical and hardness properties of the materials. It is also observed that the method during which the most significant changes occur with respect to metallurgical properties and hardness values is oxygen flame cutting method. In this method, it can be declared that hardness values differ significantly from the surface to the center and most part of the material is affected by heat released. In laser and plasma cutting methods, which are the main competitors of AWJ cutting method, the change in hardness values from the surface towards the center is continuous and heat affected zone is larger. It can be seen on the graph given in Fig. 11, losses are observed in original hardness values of the raw material in relation with the effect of heat during all methods yielding in heat generation during cutting. Measurements taken from the cut edge towards inside demonstrate that the material regains its original hardness at certain depths. Similarly, when the microstructure pictures are examined, material returns to its original structure at certain depths.

<table>
<thead>
<tr>
<th>Cutting Method</th>
<th>AISI 304 Austenitic Stainless Steel</th>
<th>Hardness (HV\textsubscript{30})</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core material</td>
<td>185.67</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Abrasive water jet cutting</td>
<td>184.50</td>
<td>0.63</td>
<td></td>
</tr>
<tr>
<td>Milling cutting</td>
<td>171.50</td>
<td>7.63</td>
<td></td>
</tr>
<tr>
<td>Hydraulic saw cutting</td>
<td>171.17</td>
<td>7.81</td>
<td></td>
</tr>
<tr>
<td>Oxygen flame cutting</td>
<td>145.33</td>
<td>21.73</td>
<td></td>
</tr>
<tr>
<td>Laser cutting</td>
<td>157.67</td>
<td>15.08</td>
<td></td>
</tr>
<tr>
<td>Plasma cutting</td>
<td>156.83</td>
<td>15.53</td>
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<tr>
<td>Water shield plasma cutting</td>
<td>163.33</td>
<td>12.03</td>
<td></td>
</tr>
<tr>
<td>Wire electro discharge cutting</td>
<td>165.83</td>
<td>10.69</td>
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</table>
Taking into consideration all methods, a continuous change in hardness values occurs in aluminum group materials, while in AISI 304 stainless steel materials, being very high in a certain zone this tendency decreases after a certain point. This can be explained with the thermal conductivity of the materials. It is known that the thermal conductivity of commercial pure aluminum and AL6061 aluminum alloys (190 kcal/s/cm/ºC), are much higher than that of steel materials and therefore heat affected zone is expected to be larger. For AISI304 austenitic stainless steel, for which the thermal conductivity (14.00 kcal/s/cm/ºC) is lower, Having greater change in hardness values in depths up to 3 mm from surface and lower beyond that zone (Fig. 11) clearly shows the effect of thermal conductivity over the heat affected zone. The size of the heat affected zone, changes depending on thermal conductivity of the cut material as well as the cutting methods. Heat affected zone is much larger in aluminum group and brass materials (103 kcal/s/cm/ºC), for which the thermal conductivities are much higher, whereas for steel materials having lower thermal conductivity and for AISI 304 austenitic stainless steel material which is one of the steel materials having lowest thermal conductivity, heat affected zone in much smaller.\(^3,20,21\) It can be concluded that, thermal conductivity of materials is also as effective on the qualities of surface obtained and neighboring zones as heat realized during cutting with different cutting methods.

**Conclusions**

The following conclusion may be drawn from the results obtained by cutting of AISI 304 stainless steel materials by different cutting methods:

(i) Regarding the effect of cutting methods on metallurgical properties of cut faces, AWJ cutting method became prominent yielding in the most favorable results.

(ii) As different heating and cooling effects occurred during application of different cutting methods constitute significant impacts on metallurgical properties of the material being tested, no heat affected zone (HAZ) occurred throughout the surface cut by AWJ and no deformation can be observed in the original structure of the material. This does not mean that there will be no change in mechanical properties related to the metallurgical properties. Besides, main reason for not having a deformation in the microstructure throughout the cut zone is that high temperatures do not occur during cutting with AWJ.

(iii) Among the eight different methods examined, when an evaluation is made based on changes in microstructure throughout the heat affected zone, “cutting with oxygen flame” is observed to be the worst method and “cutting with AWJ” as the best method. Among the applied methods, cutting with oxygen flame method is approved to be the worst one resulting in greatest change in hardness.
values of materials. Mechanical properties of materials also changes with respect to the effect of different methods on metallurgical properties of materials after cutting. As the result of the experimental studies performed, having hardness values measured on the cut faces different from the original values of materials justifies this situation.

(iv) All cutting methods applied results in a change in the hardness of materials. Changes in hardness values are observed to be different in relation with different cutting methods. This situation varies with respect to heat and temperature realized during cutting and cooling conditions.

(v) When the size of the heat affected zone is evaluated taking into account the differences in hardness values from the edges to the center based on different cutting methods, cutting with AWJ method is proved to be the most effective method with almost no differences realized. In the laser and plasma methods which are accepted to be the most important competitors of AWJ, the continuous change in hardness values from the edges to the center shows that the heat affected zone is so wider as incomparable with AWJ. This approves itself to be the most important superiority of AWJ with respect to these methods.

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