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Analysis and Influence of Acetylene and Propane Gas During Oxyfuel Gas Cutting of 1045 Carbon Steel

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Many metal-manufacturing industries include oxyfuel cutting among their manufacturing processes because cutting and welding are often required in metal-cutting processes, specifically in the fabrication of pressure vessels and storage tanks. The oxyfuel cutting process uses controlled chemical reactions to remove preheated metal by rapid oxidation in a stream of pure oxygen. Previous research has demonstrated that metal cutting surfaces varied depending on the gas used for the combustion as well as the cutting speed (Vc) used during the process. In this research, AISI 1045 carbon steel was cut using an oxyacetylene and an oxypropane cutting process. Different tests, such as surface roughness, cut drag displacement, groove width, microhardness, and microstructure, were used to analyze the influence of the Vc and the combustion flame (oxyacetylene and oxypropane). The results showed, in general, better cut surfaces when using propane gas. Also, it was demonstrated that oxyacetylene cutting is almost 85% more expensive than oxypropane cutting.

Keywords acetylene, oxyfuel gas cutting, propane, steel

1. Introduction

The oxyfuel cutting process is used as an efficient alternative cutting process in metal-manufacturing industries. The process begins by heating a small area on the surface of the metal to an ignition temperature of 760 to 870 °C with an oxyfuel gas flame. On reaching the ignition temperature, a cutting oxygen stream is then directed at the preheated spot, causing rapid oxidation of the heated metal and generating large amounts of heat (Ref 1).

Previous research has shown that the cutting speed (Vc) is influenced by the amount of oxygen used in the cutting process and that the type of gas used for combustion has an influence on the time needed to start the cutting process, because the flame determines the preheating of the metal to be cut (Ref 2-5). Also, when the properties and dimensional accuracy of a gas-cut plate are acceptable, oxyfuel cutting can replace a costly machining operation when done under specific cutting variables and where very good roughness (Ra) can be achieved (Ref 1).

Regarding the consumption and cost of the fuels used in oxyfuel gas cutting, many workers have arrived at the same conclusion; the use of propane gas is very economical. At present in developed countries in America and Europe, the main gas used in different thermal cutting processes is propane, although each country is looking for a gas that can be substituted for acetylene, because it is explosive, contains contaminates, and is harmful to the operators (Ref 6).

Research that compares the cost of gasoline as an alternative combustion fuel in an oxyfuel gas cutting process concluded that the oxyfuel gas cutting equipment works faster and introduces less heat into the piece being cut, so there is less deformation. All of the other combustion fuels that cut more slowly (especially propane gas) introduce more heat to the piece, producing greater deformation (Ref 7).

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2. Experimental Procedure

2.1 Work Piece Materials and Characteristics

AISI 1045 carbon steel plate (thickness [*t*] 25.4 mm) was used for the experiments. The chemical composition and the mechanical properties are shown in Tables 1 and 2, respectively.

The cutting variables used for the experiments are shown in Table 3. Figure 1 shows the scheme of the oxyfuel cutting process, where the distance (*B*) between the cutting tip and the metal surface is shown as well as the cutting direction.

Nomenclature

B	Distance between cutting tip and the workpiece, mm
Da	Groove width, mm
Da_a	Groove width average, mm
Dc	Cut drag displacement, mm
Dc_a	Cut drag displacement average, mm
Dsc	Distance from the cut surface to the center of the specimen, mm
HBN	Brinell hardness number
HV	Vickers hardness
Ra_X	Roughness, μm ($X = A$, B, or C)
Ra_a	Roughness average, μm
S_u	Ultimate tensile strength, MPa
S_y	Yield tensile strength, MPa
t	Thickness of the specimen, mm
Vc	Cutting speed, mm/min

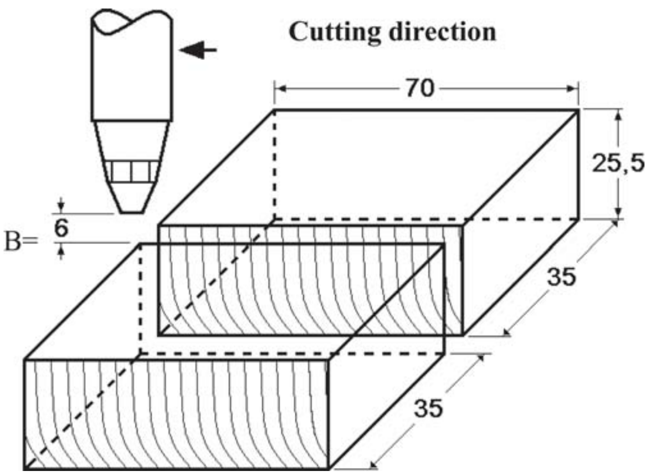

Fig. 1 Scheme of the specimens obtained after the oxyfuel cutting process of an AISI 1045. Cutting direction and distance (B) between the cutting tip and the workpiece are also shown.

Table 1 Chemical composition of AISI 1045 steel

Material	%C ± 0.001	%Mn ± 0.001	%S ± 0.001
AISI 1045	0.473	0.837	0.058

Table 2 Mechanical properties of AISI 1045 steel

Material	HBN(a)	S_y, MPa	S_u, MPa
AISI 1045	174	490	814

(a) HBN, ∅ 10 mm; load 3000 kg

Table 3 Cutting parameters for oxyfuel cutting process for an AISI 1045 steel

		Pressure, psi			
Gas	Vc(a), m/min	Gas	Oxygen (pre-heat process)	Oxygen (cut process)	*B*, mm
Acetylene	50–450	7.3	36	65	6
Propane	50–450	2.9	36	58	6

Note: *B*, distance between the cutting tip and the workpiece. (a) Vc is reported in increments of 50 mm/min

The surface Ra was measured using a Mitutoyo Surftest (model 211) with a resolution of ± 0.01 μm and a cutoff of 0.25 mm.

3. Research Approach

3.1 Cut Specimens

Once all the cutting variables were established, 18 specimens were obtained following the scheme of the cut shown in Fig. 1. The Ra, cut drag displacement (Dc), and groove width (Da), as well as microhardness and microstructure, were evaluated for each cutting condition.

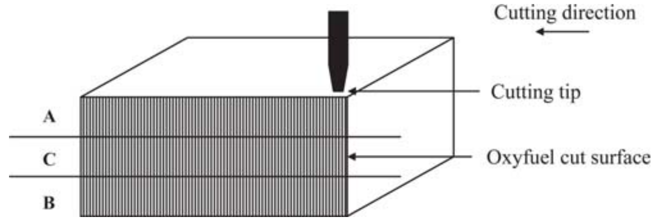

Fig. 2 Areas where the surface Ra was measured. (A) Area closest to the cutting tip; (B) area furthest from the cutting tip; (C) central area

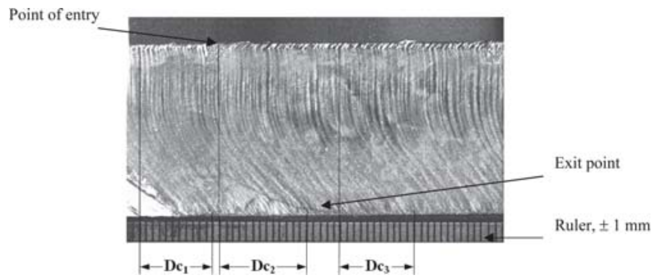

Fig. 3 Scheme of the Dc measurement

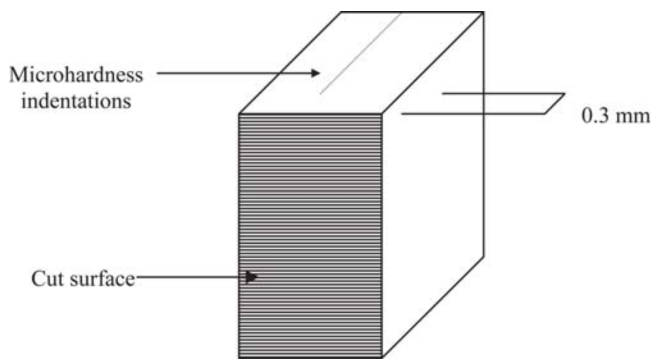

Fig. 4 Scheme of the microhardness test conducted on specimens cut with oxyfuel cutting process

3.2 Surface Roughness Measurement

Once the sample plate was cut using the oxyfuel cutting process with oxyacetylene or oxypropane as the fuel, each specimen was measured for surface Ra. Different areas of the cut surface were evaluated for Ra: (A) area closest to the cutting tip; (B) area furthest from the cutting tip; and (C) central area, located between areas A and B, as shown in Fig. 2. To obtain an average value of surface Ra, each area was measured six times and extreme values were ignored.

3.3 Cut Drag Displacement Measurement

The horizontal distance between the point of entry and the exit of the flow is called drag. The Dc is a rough measure of the cut quality and the economy in oxygen consumption (Ref 1). Measurements were made at points between the beginning and the end of the crest using a POZ MWM microscope. A measurement ruler with a ±1 mm resolution was placed on the bottom side of each specimen, to measure the Dc. Three measurements were performed for each specimen, as shown in Fig. 3.

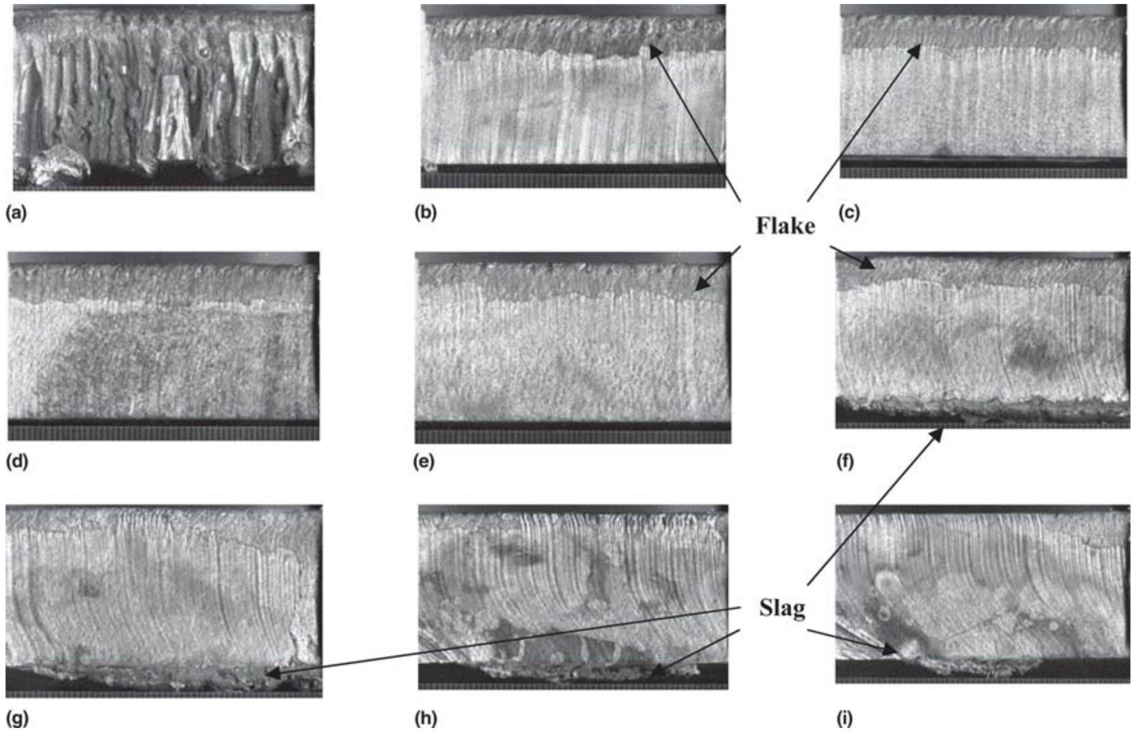

Fig. 5 AISI 1045 specimens cut with oxyacetylene: (a) 50 mm/min; (b) 100 mm/min; (c) 150 mm/min; (d) 200 mm/min; (e) 250 mm/min; (f) 300 mm/min; (g) 350 mm/min; (h) 400 mm/min; (i) 450 mm/min

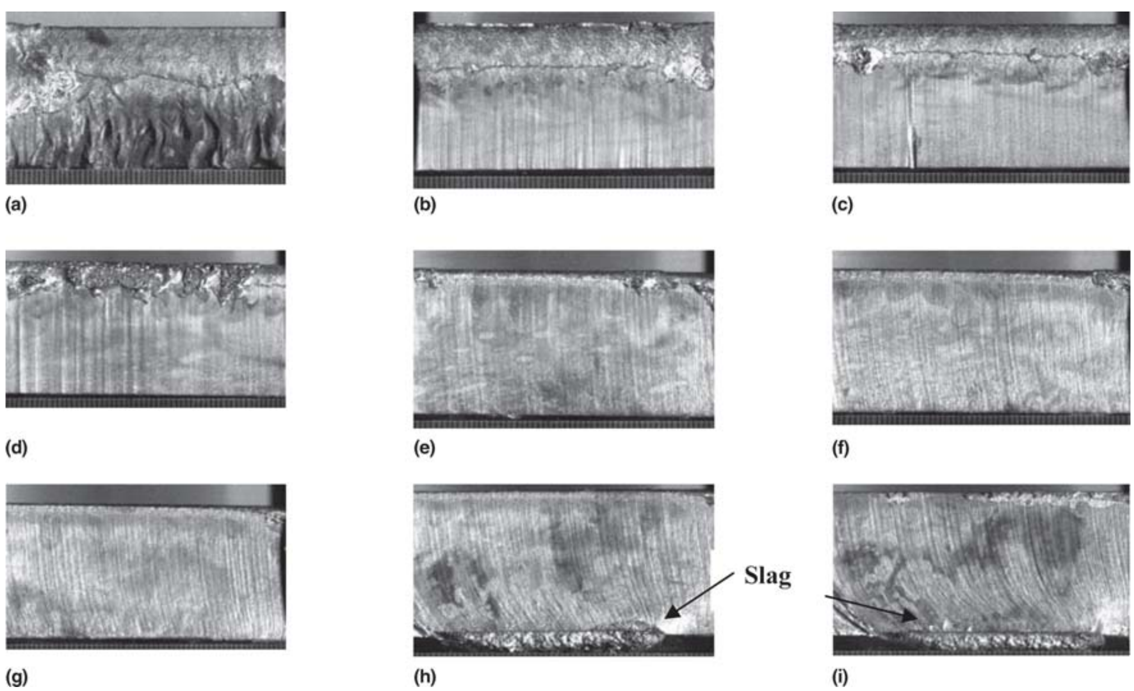

Fig. 6 AISI 1045 specimens cut with oxypropane: (a) 50 mm/min; (b) 100 mm/min; (c) 150 mm/min; (d) 200 mm/min; (e) 250 mm/min; (f) 300 mm/min; (g) 350 mm/min; (h) 400 mm/min; (i) 450 mm/min

3.4 Groove Width Measurement

This value was also measured using a POZ MWM microscope. The procedure consisted of counting the number of grooves in an interval equal to 20 mm. To obtain a groove average, the 20 mm interval was divided by the number of grooves observed in that interval. Three measurements also were made on each specimen to determine this value.

3.5 Microstructure and Microhardness Studies

Microstructural studies were conducted on each specimen following the ASTM E 3-01 standard (Ref 8) to compare possible changes in microstructure due to variations in Vc and fuel gas used for combustion.

Microhardness tests were conducted following the ASTM E-384 and E-389 standards (Ref 9, 10). These tests were conducted on each specimen on a plane perpendicular to the cut surface, starting 0.3 mm from the cut edge, as observed in Fig. 4.

3.6 Consumption and Cost of Gas and Oxygen

The consumption of gas was determined from tables obtained from the cutting equipment manufacturer (Messer Griesheim, Sulzbach, Germany), where the gas pressure for various sizes and styles of cutting torches and tips, and the recommended Vc for them, is reported. Also, a relationship between cylinder pressure (psi) obtained from the gas and oxygen manometers, and the consumption of gas and oxygen (m^3/h) are reported.

4. Results and Discussion

4.1 Cut Specimens

The specimens were cut using the oxyfuel cutting process, and the results of the cut surface using oxyacetylene at different Vc values (Fig. 5) and those using oxypropane at different Vc values (Fig. 6) are shown.

From Fig. 5 and 6, morphological differences are seen to be due to changes in the combustion gas (acetylene or propane) and the Vc. The first noticeable difference in the specimens is the presence of flakes.

Specimens cut with oxyacetylene (Fig. 5) showed some flakes, which were very easy to remove. The flakes occurred on the upper edge of the specimen at Vc values <300 mm/min (Ref 11).

Specimens cut with oxypropane, in general, did not show the flakes but instead were slightly curved along the upper edge. This is probably due to the fact that the flame obtained with oxyacetylene combustion has a different heat distribution compared with the flame obtained with oxypropane. For acetylene gas, a heat distribution profile indicates that almost one-third of the heat is concentrated in the primary flame while the rest is concentrated in the secondary flame, compared with propane gas, where one-tenth of the heat is concentrated in the primary flame (Ref 12). As a result, acetylene gas produces a more focused flame, resulting in a better surface on the upper edge when using Vc values <250 mm/min.

Another morphological difference found in this study is the presence of slag in some specimens, which is not desired in the final product and is not easy to remove (Ref 11).

Slag can be observed on the lower edge of the specimens cut with oxyacetylene at Vc values of ≥300 mm/min (Fig. 5f–i). For specimens cut with oxypropane, the slag appears at Vc values of ≥400 mm/min (Fig. 6h, i).

The presence of slag at high Vc (i.e., ≥400 mm/min) is probably due to the fact that the cutting time is too short to drag all this material away from the cutting area. The difference in time needed to remove the slag when using oxyacetylene or oxypropane may be due to the nature of the flame being used (Ref 1).

Also, the slag causes extra heating of the specimen in the surrounding area. This additional heat can cause possible changes in the mechanical properties of the material that has been cut, as well as possible distortion in adjacent areas. From Fig. 5(h) and (i) and Fig. 6(h) and (i), the specimens exhibit a different "color" of cut surface in the area near the location of the slag.

Table 4. Roughness and average roughness of the different areas of the specimens cut using oxyfuel cutting process

Gas	Vc, mm/min	Ra_A, ±0.01 μm	Ra_B, ±0.01 μm	Ra_C, ±0.01 μm	Ra_a, ±0.03 μm
Acetylene	50	(a)	(a)	(a)	(a)
	100	10.3	9.4	12.8	10.80
	150	8.73	12.34	10.25	10.44
	200	10.5	8.58	9.11	9.40
	250	8.41	9.02	11.64	9.70
	300	9.93	6.56	9.43	8.64
	350	10.83	10.53	9.24	10.20
	400	8.86	8.97	11.92	9.92
	450	9.64	9.97	10.56	10.05
Propane	50	(a)	(a)	(a)	(a)
	100	7.17	7.43	7.27	7.29
	150	6.81	6.13	7.14	6.69
	200	5.21	5.06	6.09	5.45
	250	5.92	5.69	4.98	5.53
	300	6.12	5.08	4.44	5.21
	350	7.66	7.83	8.05	7.85
	400	8.62	9.2	8.76	8.86
	450	9.98	7.28	10.07	9.20

Note: Ra_A, roughness for area A; Ra_B, roughness for area B; Ra_C, roughness for area C; Ra_a, roughness average. (a) High surface Ra value due to low Vc

4.2 Surface Roughness

Table 4 shows the average surface Ra of the AISI 1045 steel in each area (A, B, and C) and the total average Ra of the cut surface.

Figure 7 shows the influence of the Vc and the gas used for combustion on the surface Ra of AISI 1045 carbon steel.

In Fig. 7, it was observed that at a low Vc (e.g., 50 mm/min), the value of Ra was so high that it was not possible to measure it. As the Vc was increased, the Ra decreased to a minimum, and then later increased again.

When analyzing Fig. 7, and comparing the results of Ra between specimens cut with oxyacetylene and oxypropane, it was noted that, in general, better surfaces were obtained when using propane gas as the combustion fuel, especially when the Vc values were between 200 and 300 mm/min.

4.3 Cut Drag Displacement

Table 5 shows the results of Dc after the oxyfuel cutting of AISI 1045 steel using oxyacetylene and oxypropane. Figure 8 shows the influence of the Vc on the Dc for different cutting conditions.

From the data in Fig. 8, Dc increases with increasing Vc. This is probably due to the fact that because the Vc is increased, less oxygen is available at the bottom of the cut, causing poor quality of the surface (Ref 1). For the tests with Vc values <200 mm/min, the Dc was, in general, < 1 mm. Also, it was observed that Dc decreased when using oxypropane.

4.4 Groove Width

Table 6 shows the results of the Da obtained after cutting AISI 1045 steel with oxyacetylene and oxypropane. Figure 9

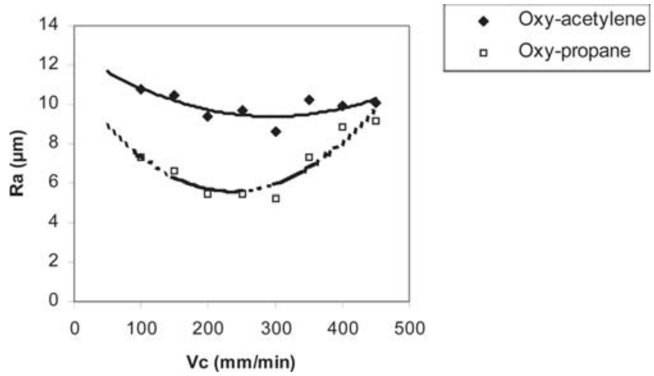

Fig. 7 The surface Ra versus Vc for AISI 1045 cut with oxyacetylene and oxypropane

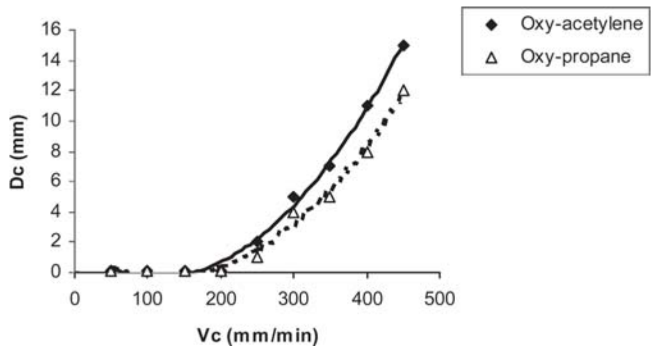

Fig. 8 The Dc versus Vc for AISI 1045 specimens cut with oxyacetylene and oxypropane

Table 5. Cut drag displacement and average obtained in AISI 1045 carbon steel when cut with oxyfuel cutting process using acetylene or propane gas as combustion gas

Gas	Vc, mm/min	Dc_1, ±1 mm	Dc_2, ±1 mm	Dc_3, ±1 mm	Dc_a, ±3 mm
Acetylene	50	0	0	0	0
	100	0	0	0	0
	150	0	0	0	0
	200	0	0	0	0
	250	2	2	2	2
	300	5	5	4	5
	350	7	6	8	7
	400	11	11	10	11
	450	14	16	14	15
Propane	50	0	0	0	0
	100	0	0	0	0
	150	0	0	0	0
	200	0	0	0	0
	250	1	1	1	1
	300	4	3	4	4
	350	5	5	4	5
	400	8	8	9	8
	450	13	13	11	12
	500	15	14	13	14

Note: DC_1, Dc of specimen 1; Dc_2, Dc of specimen 2; Dc_3, Dc of specimen 3; Dc_a, Dc average

shows the influence of the Vc on Da for different cutting conditions.

In Fig. 9, Da increased with increasing Vc. This tendency is more remarkable at Vc values >250 mm/min when using both oxyacetylene and oxypropane. Better results were observed when using oxypropane at Vc values of >300 mm/min.

When comparing the slopes of Fig. 9 (Da versus Vc) with the slope of Fig. 7 (surface Ra versus Vc), it was observed that the curve starts to increase suddenly at a Vc of 300 mm/min. With this result, it was possible to deduce a relationship between surface Ra and Da.

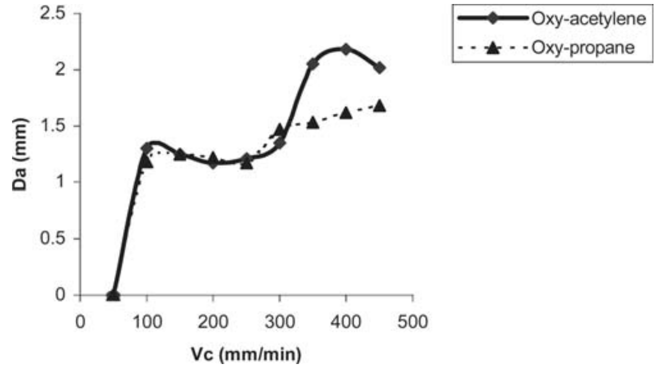

Fig. 9 The Da versus Vc for AISI 1045 specimens cut with oxyacetylene and oxypropane

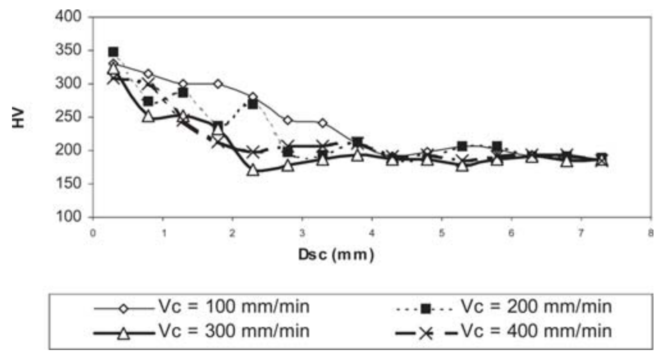

Fig. 10 The HV versus distance from the cut surface to the center of the specimen (Dsc) for AISI 1045 specimens cut with oxyacetylene using different Vcs

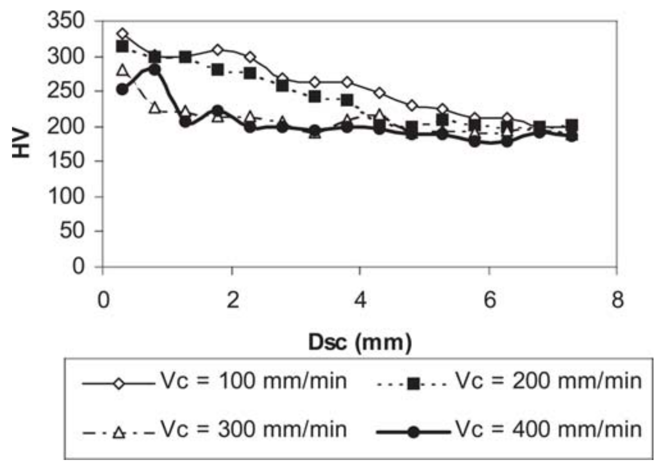

Fig. 11 The HV versus distance from the cut surface to the center of the specimen (Dsc) for AISI 1045 specimens cut with oxypropane using different Vcs

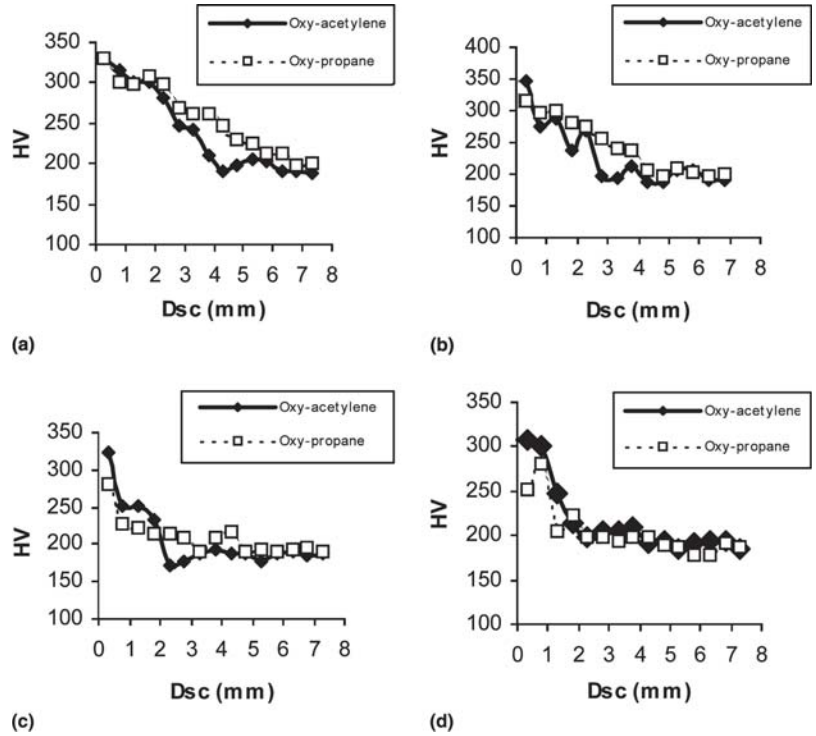

Fig. 12 The HV versus distance from the cut surface to the center of the specimen (Dsc) for AISI 1045 specimens cut with oxyacetylene and oxypropane: (a) Vc, 100 mm/min; (b) Vc, 200 mm/min; (c) Vc, 300 mm/min; (d) Vc, 400 mm/min

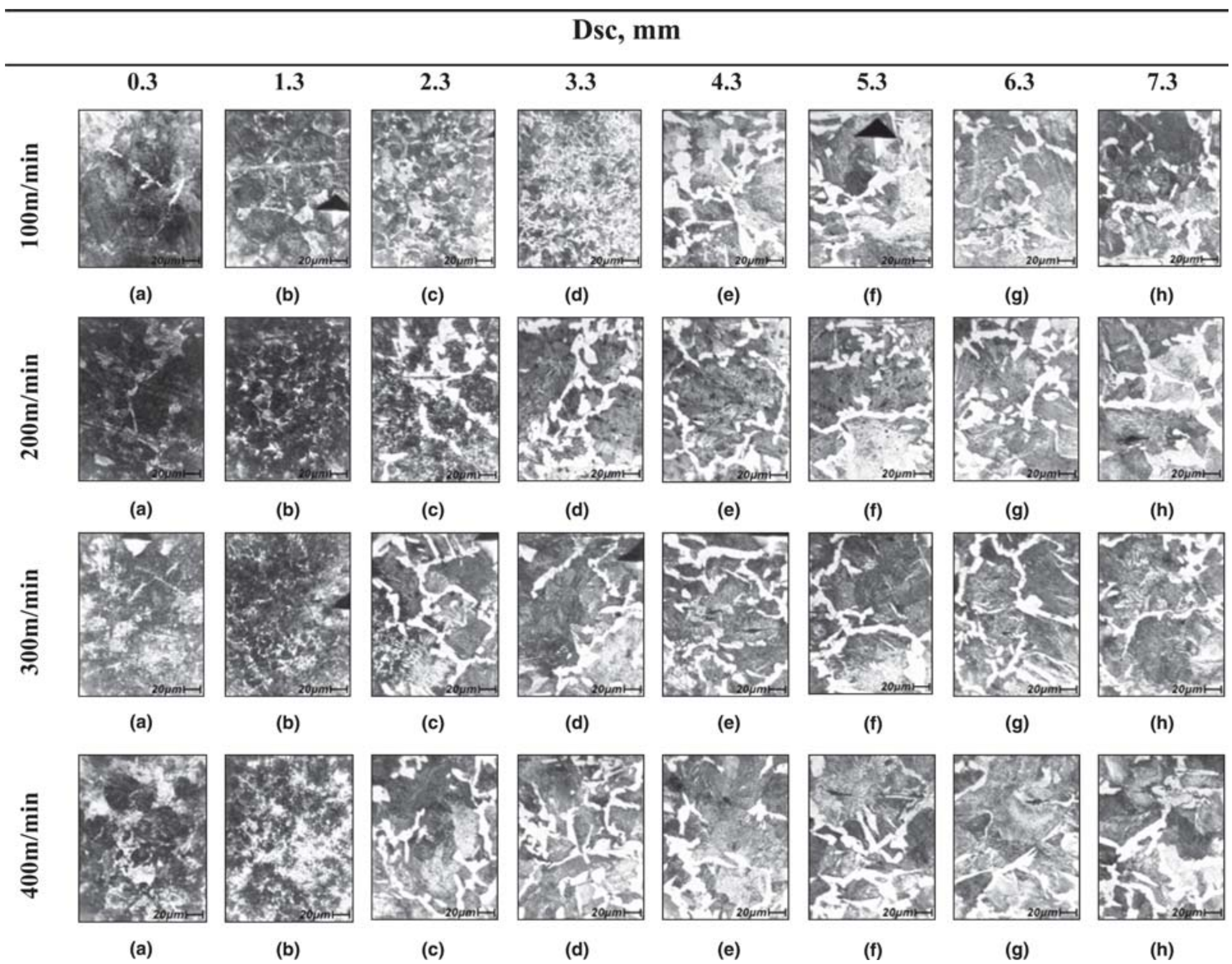

Fig. 13 Microstructure of the heat affected zone of the AISI 1045 specimens cut with oxyacetylene under different cutting conditions

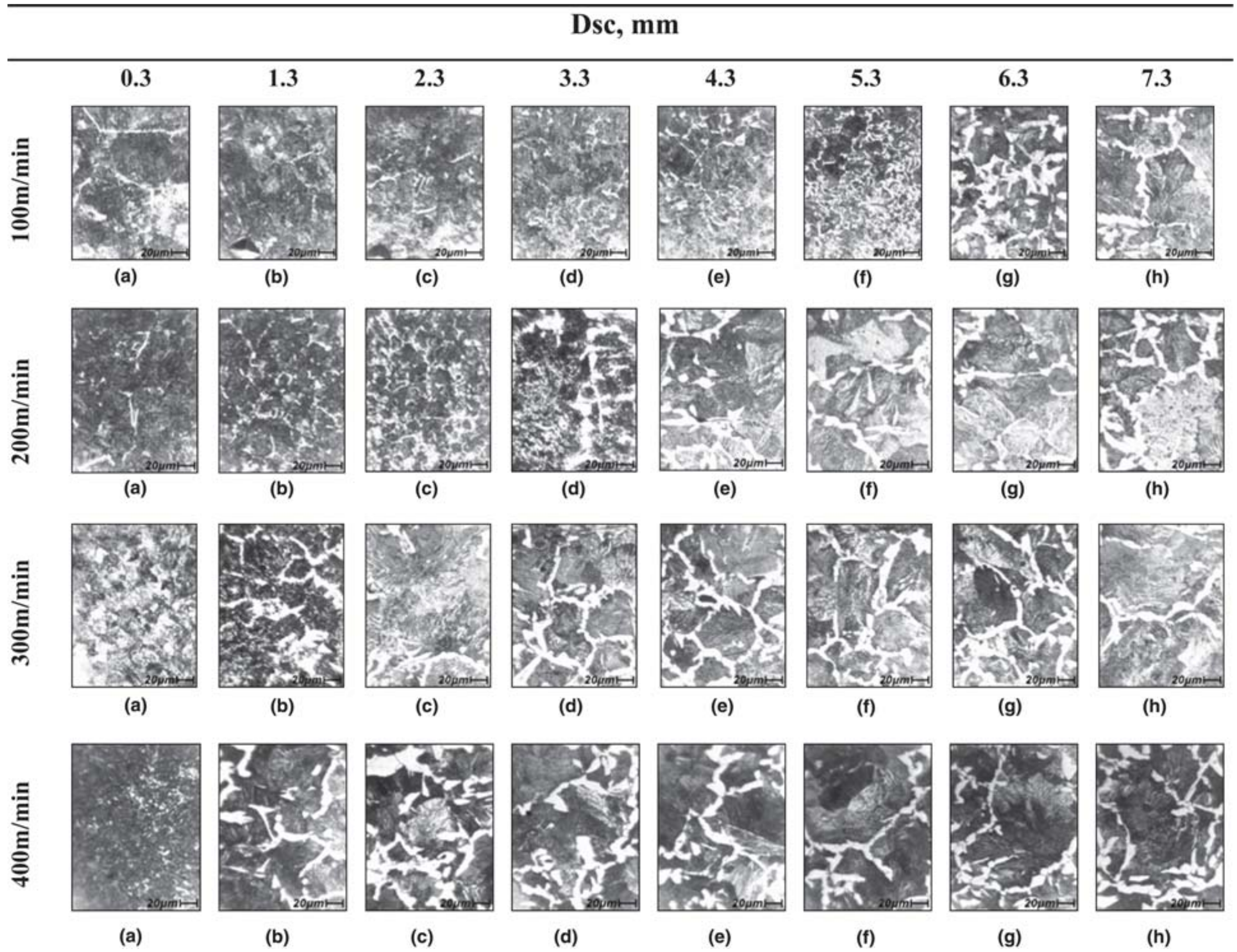

Fig. 14 Microstructure of the heat affected zone of the AISI 1045 specimens cut with oxypropane under different cutting conditions

Table 6 Cut drag displacement and average obtained in AISI 1045 carbon steel when cut with oxyfuel cutting process using acetylene or propane gas as combustion gas

Gas	Vc, mm/min	Da_1, ±0.05 mm	Da_2, ±0.05 mm	Da_3, ±0.05 mm	Da_a, ±0.15 mm
Acetylene	50	0	0	0	0
	100	1.3	1.35	1.25	1.30
	150	1.15	1.35	1.25	1.25
	200	1.25	1.2	1.05	1.17
	250	1.25	1.2	1.05	1.21
	300	1.15	1.25	1.3	1.35
	350	2.1	1.9	2.15	2.05
	400	2.45	1.9	2.2	2.18
	450	1.95	2	1.95	2.02
Propane	50	0	0	0	0
	100	1.15	1.25	1.15	1.18
	150	1.35	1.15	1.25	1.25
	200	1.3	1.2	1.15	1.22
	250	1.15	1.15	1.2	1.17
	300	1.85	2.15	1.9	1.47
	350	1.5	1.4	1.7	1.53
	400	1.6	1.55	1.7	1.62
	450	1.7	1.6	1.75	1.68

Note: Da_1, Da of specimen 1; Da_2, Da of specimen 2; Da_3, Da of specimen 3; Da_a, Da average

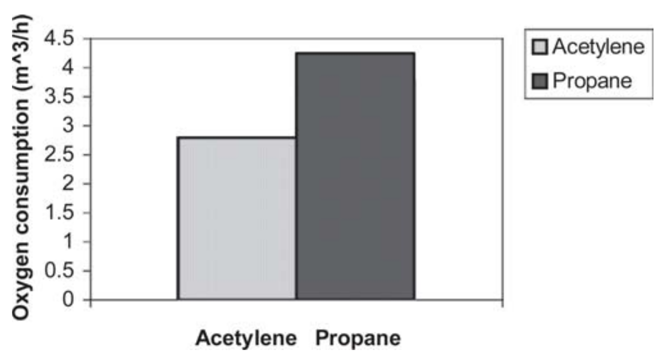

Fig. 15 Oxygen consumption when using acetylene and propane as combustion gases

4.5 Microhardness and Microstructure Analysis

As is well known, the oxyfuel cutting process involves a thermal cycle that produces changes in the microstructure and mechanical properties of the cut specimen (Ref 12).

When conducting microhardness tests on AISI 1045 steel specimens cut under different cutting conditions, it was observed that a variation of microhardness occurred from the area closest to the cut surface to the center of the specimen.

Table 7 shows microhardness values from the edge of the cut surface toward the center of the specimen. Fifteen mea-

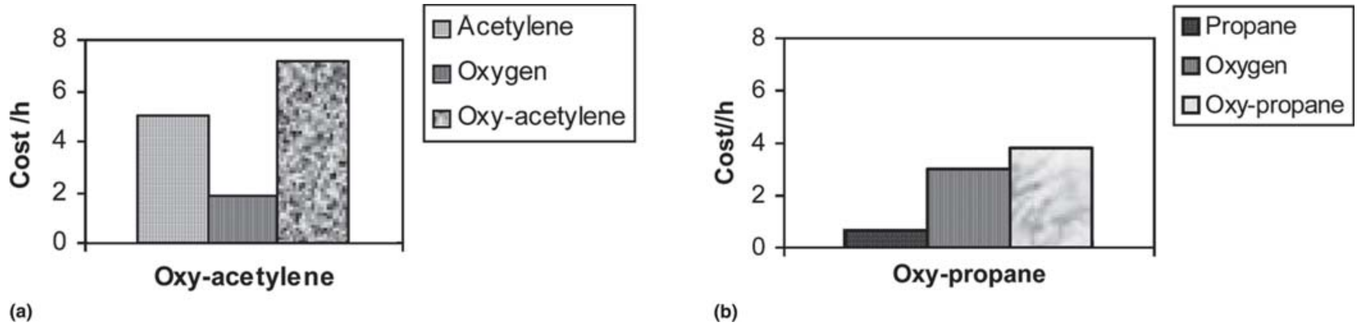

Fig. 16 Cost per hour of each gas and their mixture: (a) oxyacetylene; (b) oxypropane

Table 7 Vickers hardness obtained from the cut surface toward the center of the specimens of AISI 1045 steel cut under different cutting conditions

	Dsc, mm														
Gas/Vc, m/min	0.3	0.8	1.3	1.8	2.3	2.8	3.3	3.8	4.3	4.8	5.3	5.8	6.3	6.8	7.3
Acetylene/100	331.0	315.4	299.9	300.9	280.9	246.5	241.5	209.8	190.8	198.1	205.7	201.8	190.8	190.1	187.3
Acetylene/200	347.7	274.7	287.4	236.5	268.7	198.1	194.4	213.9	198.1	186.9	205.7	205.7	190.8	192.1	190.1
Acetylene/300	323.0	251.8	251.8	231.7	171.2	177.4	187.3	194.4	190.8	187.5	177.4	187.3	190.8	183.9	187.3
Acetylene/400	30.0	300.9	246.6	213.9	198.1	205.7	205.7	209.8	194.4	190.8	183.9	190.8	192.7	194.4	183.9
Propane/100	331.0	300.9	299.3	308.0	298.7	268.7	262.9	262.9	246.6	229.0	225.7	212.5	211.7	198.1	199.7
Propane/200	315.4	298.0	298.5	280.9	274.7	257.3	241.7	237.3	205.7	198.1	209.8	202.7	198.1	199.8	201.8
Propane/300	280.9	227.1	222.5	213.9	213.9	208.1	190.8	209.8	218.1	190.8	194.4	190.8	193.8	195.8	189.1
Propane/400	251.8	280.9	205.7	222.5	198.1	198.9	194.4	198.1	197.4	189.8	187.9	179.2	178.3	190.8	187.4

Note: Dsc, distance from the cut surface to the center of the specimen

surements were made at 0.5 mm intervals starting at 0.3 mm from the cut surface (Fig. 4).

Figure 10 shows how the Vickers hardness (HV) changes from the cut surface toward the center of the specimen when using oxyacetylene at different Vc values. Figure 11 shows the HV from the cut surface toward the center of the specimen when using oxypropane.

Analyzing the data in Fig. 10 and 11, the hardness decreased gradually from the cut surface to the center of the specimens. This indicates a possible change in microstructure due to heat transfer, because heat generated by the oxyfuel cut process can degrade the metallurgical properties of the work material adjacent to the cut edge (Ref 1). Higher values of hardness were obtained near the cut surface when using oxyacetylene, and apparently no changes in hardness were obtained at a distance ≥3 mm from the cut surface for both oxyacetylene and oxypropane.

Figure 12 shows in more detail the changes in hardness when using oxyacetylene and oxypropane. In Fig. 12, it is seen that, in general, oxypropane has more influence on the hardness at a Vc of <400 mm/min (Fig. 12a-c). This is probably due to the fact that the acetylene concentrates more heat in a smaller volume leading to a reduced transformation area when using this gas (Ref 1). For Vc values >400 mm/min, apparently, both gases behave in the same way.

4.6 Microstructure of the Heat-Affected Zone

Figures 13 and 14 show the AISI 1045 steel microstructures obtained at a distance 0.3 mm from the cut edge, progressing sequentially at 1 mm intervals toward the center of the specimen using different oxyfuel cutting conditions.

In Fig. 13(a) to (d) and Fig. 14(a) to (d), general changes in microstructure can be observed for the different conditions, corresponding to a distance of 3.3 mm from the cut surface. From this point (3.3 mm), there is little difference in the microstructure, indicating that this area was not affected by the heat. This is verified when comparing these results with hardness changes (Fig. 10, 11), where only minor changes in hardness are observed at a distance >3.3 mm from the cut surface for both oxyacetylene and oxypropane. These results match those obtained for hardness changes (Fig. 10, 11), where at a distance of 3.3 mm from the cutting edge apparently no changes in hardness were found.

4.7 Gas Consumption

In oxyfuel cutting, fuel gas consumption varies due to the fact that the fuels have different combustion and flow characteristics. Figure 15 shows the variation of oxygen needed for the combustion of acetylene and propane in oxyfuel cutting, where propane gas consumes approximately 43% more oxygen than acetylene gas.

Figure 16 shows the cost per hour when using oxyacetylene or oxypropane. In Fig. 16, even though propane gas needs more oxygen for combustion, acetylene gas is more expensive than propane; thus, the total operational cost of using oxyacetylene is ~85% more than that when using oxypropane. This is a very important economical factor that must be taken into account when deciding which combustion gas to use.

5 Conclusions

- The best surface Ra was obtained when using oxypropane due to the nature and characteristics of its flame. For low

Vc values (50 mm/min), and for both acetylene and propane, the surface Ra values of the cut surface were so high that they were impossible to measure due to the measurement range of the equipment. Apparently, there was a range between 200 and 300 mm/min where better surface Ra was obtained due to the fact that the cutting time was enough to drag all the material away from the cutting area.

- Less slag adherence to the cut surface was found when using oxypropane due to the heat distribution of its flame. The presence of slag on the cut surface increases the heat input of the oxyfuel cut surface.
- The Dc decreases when using propane gas due to the nature of the flame. A Vc of <200 mm/min produced a Dc of <1 mm.
- The Da increases when the Vc is increased, with the Da being smaller when using oxypropane at a Vc of $\geq$300 mm/min due to the nature of its flame.
- Hardness values are higher near the cut surface when using the oxyacetylene process because this flame has one third of its heat concentrated in the primary flame, producing a more focused flame. Hardness values decrease from the cut surface toward the center of the piece because heat transfer dissipates along this space. Oxypropane has more influence on hardness when using a Vc of <400 mm/min. At a Vc of 400 mm/min, oxyacetylene and oxypropane seem to have the same influence on hardness.
- Combustion gas and Vc influence microstructural changes due to the nature of the flame being used and the time given for the cut. There are no apparent changes in microstructure at a distance >3.3 mm from the cut surface due to the dissipation of the heat.
- Oxyacetylene is almost 85% more expensive then oxypropane because it needs more oxygen for its combustion.

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