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MICROSTRUCTURE CHANGES OF CONSTRUCTIONAL STEEL CAUSED AFTER CUTTING WITH OXYGEN

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Abstract: *The article deals with the technology of thermal cutting material with oxygen. In the firs part, it deals with the theoretical knowledge of the principle of cutting with oxygen and the current use of the technology in industry. The cut of products using this technology is perpendicular and accurate but using it affects the structure by microstructural changes and the depth of heat affected zone (HAZ). The heat used in process of cutting the material affects its microstructure.*

Key words: *cutting, oxygen, microstructure, heat affected zone (HAZ).*

1. INTRODUCTION

The cutting of materials is possible to class in a group of technologies for preparing of production. We understand in this term technologies of cutting which use the principles of local meltdown, burning or steaming, and combinations of these principles. Energy which is necessary for thermal processes is delivered from different thermal sources. The group of cutting technologies includes traditional mechanical principles of cutting too. In generally we can apply thermal cutting for all range of constructional materials: plain steel, plain carbon steel, cor-ten steel, high-alloy steel and nickels alloys, nonferrous metals and their alloys (aluminum, copper, brass,…), high-reactive materials and their oxygen sensitive alloys (magnesium, titanium, …), nonmetallic materials (plastic, composites, wood, paper, glass, …). The first material which was cut of cutting with oxygen is plain steel. When people discovered technology of laser cutting, we can cut whichever electric conductive and nonconductive materials with extremely high affinity of oxygen or nitrogen. In the industry are used three basic methods of thermal cutting: oxygen cutting, plasma cutting and laser cutting.

–Although oxygen cutting is generally viewed as a mature uncomplicated process, those who work with it realize all too well that making it perform properly is no simple matter. Experienced operators can achieve a level of cut quality that rivals a machined surface, and do it in a fraction of the time and at a fraction of the cost of hard tooling. Consistently reaching that quality, however, requires an understanding of the many factors that are at work, their direct effect on quality, and their interaction with each other. For many operators that can only be achieved through years of hands-on experience.

2. CUTTING WITH OXYGEN

In practice is the cutting with oxygen most useful technology for cutting of plain steel and low carbon steel with thickness 10 – 100 mm. Cutting edge and surface is not very good by this technology but for low nominal price is very popular. For all that, this technology of cutting is known, the development is not stopped. Today, the area of discover is to increase the speed of cutting with reduction of fuel consumption.

2.1. Cutting with oxygen

Oxygen is used for cutting and welding. For cutting, the set-up is a little different. A cutting torch has a 60 or 90 degree angled head with orifices placed around a central jet. The outer jets are for preheat flames of oxygen and acetylene. The central jet carries only oxygen for cutting. The use of a number of preheating flames, rather than a single flame makes it possible to change the direction of the cut as desired without changing the position of the nozzle or the angle which the torch makes with the direction of the cut, as well as giving a better preheat balance. Manufacturers have developed custom tips for map, propane, and polypropylene gases to optimize the flames from these alternate fuel gases.

The flame is not intended to melt the metal, but to bring it to its ignition temperature.

The torch's trigger blows extra oxygen at higher pressures down the torch's third tube out of the central jet into the workpiece, causing the metal to burn and blowing the resulting molten oxide through to the other side.

Fig. 1. Oxygen Rich Butane Torch Flame [3].

Fig. 2. Fuel Rich Butane Torch Flame [3].

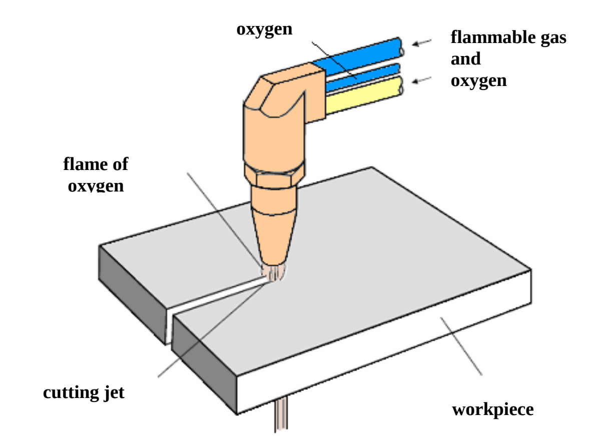

Fig. 3. The principle of cutting with oxygen [1].

The ideal kerf is a narrow gap with a sharp edge on either side of the workpiece; overheating the workpiece and thus melting through it causes a rounded edge.

Cutting is initiated by heating the edge or leading face (as in cutting shapes such as round rod) of the steel to the ignition temperature (approximately bright cherry red heat) using the pre-heat jets only, then using the separate cutting oxygen valve to release the oxygen from the central jet. The oxygen chemically combines with the iron in the ferrous material to instantly oxidize the iron into molten iron oxide, producing the cut. Initiating a cut in the middle of a workpiece is known as piercing.

It is worth noting several things at this point [1]:

- The oxygen flowrate is critical — too little will make a slow ragged cut; too much will waste oxygen and produce a wide concave cut. Oxygen Lances and other custom made torches do not have a separate pressure control for the cutting oxygen, so the cutting oxygen pressure must be controlled using the oxygen regulator.

The oxygen cutting pressure should match the cutting tip oxygen orifice. Consult the tip manufacturer's equipment data for the proper cutting oxygen pressures for the specific cutting tip.

- The oxidation of iron by this method is highly exothermic. Once started, steel can be cut at a surprising rate, far faster than if it was merely melted through. At this point, the pre-heat jets are there purely for assistance. The rise in temperature will be obvious by the intense glare from the ejected material, even through proper goggles. (A thermic lance is a tool which also uses rapid oxidation of iron to cut through almost any material.)
- Since the melted metal flows out of the workpiece, there must be room on the opposite side of the workpiece for the spray to exit. When possible, pieces of metal are cut on a grate that lets the melted metal fall freely to the ground. The same equipment can be used for oxyacetylene blowtorches and welding torches, by exchanging the part of the torch in front of the torch valves.

For a basic oxy-acetylene rig, the cutting speed in light steel section will usually be nearly twice as fast as a petrol-driven cut-off grinder. The advantages when cutting large sections are obvious – an oxy-fuel torch is light, small and quiet and needs very little effort to use, whereas a cut-off grinder is heavy and noisy and needs considerable operator exertion and may vibrate severely, leading to stiff hands and possible long-term repetitive strain injury. Oxy-acetylene torches can easily cut through ferrous materials in excess of 50 mm (2 inches). Oxygen Lances are used in scrapping operations and cut sections thicker than 200 mm (8 inches). Cut-off grinders are useless for these kinds of application.

Robotic oxy-fuel cutters sometimes use a high-speed divergent nozzle. This uses an oxygen jet that opens slightly along its passage. This allows the compressed oxygen to expand as it leaves, forming a high-velocity jet that spreads less than a parallel-bore nozzle, allowing a cleaner cut. These are not used for cutting by hand since they need very accurate positioning above the work. Their ability to produce almost any shape from large steel plates gives them a secure future in shipbuilding and in many other industries.

Oxy-propane torches are usually used for cutting up scrap to save money, as LPG is far cheaper joule-for-joule than acetylene, although propane does not produce acetylene's very neat cut profile. Propane also finds a place in production, for cutting very large sections.

Oxy-acetylene can only cut low to medium carbon steels and wrought iron. High carbon steels cannot be cut because the melting point is very close to the temperature of the flame and so the slag from the cutting action does not eject as sparks, but rather mixes with the clean melt near the cut. This keeps the oxygen from reaching the clean metal and burning it. In the case of cast iron graphite between the grains and the shape of the grains themselves interfere with cutting action of torch.

Welding torch [3]. A welding torch head is used to weld metals. It can be identified by having only one or two pipes running to the nozzle and no oxygen-blast trigger and two valve knobs at the bottom of the handle letting the operator adjust the oxygen flow and fuel flow.

Cutting torch [3]. A cutting torch head is used to cut metal. It is similar to a welding torch, but can be identified by having three pipes that go to a 90 degree nozzle and by the oxygen-blast trigger.

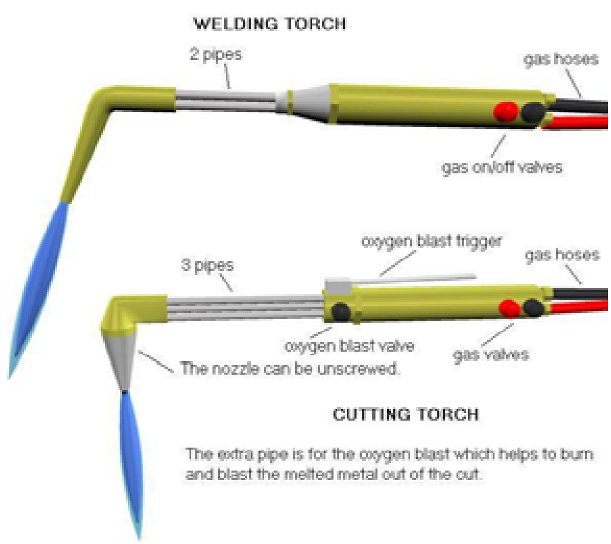

Fig. 4. Difference between welding and cutting torch. [3]

Only iron and steel can be cut using this method. The metal is first heated by the flame until it is cherry red. Once this temperature is attained, oxygen is supplied to the heated parts by pressing the "oxygen-blast trigger".

This oxygen reacts with the metal, forming iron oxide and producing heat. It is this heat which continues the cutting process. The cutting torch only heats the metal to start the process; further heat is provided by the burning metal.

The melting point of the iron oxide is around half of that of the metal; as the metal burns, it immediately turns to liquid iron oxide and flows away from the cutting zone. However, some of the iron oxide remains on the work piece, forming a hard "slag" which can be removed by gentle tapping, and/or a grinder.

2.2. Oxygen and acetylene

Oxygen, which makes up about 21 percent of the air we normally breathe, as well as about 90 percent by weight of all the water on earth, may be considered the most important element in the universe. Without it, there would be no life as we know it. Every living animal ”burns” oxygen with carbon and hydrogen to produce the energy that it needs in order to live, grow, and move. Fortunately for the animal kingdom, all green plants produce more oxygen than they consume, so that the reservoir of oxygen in our atmosphere remains at a constant level from century to century. Oxygen not only combines with carbon and hydrogen to produce energy (heat), but combines with most of the other elements found in the universe, including all metals. Fortunately, its reaction with most elements and compounds takes place very slowly or not at all at normal temperatures. However, almost everything made up predominantly of carbon and hydrogen (coal, wood, petroleum products) has a "kindling temperature". Once that temperature is reached, "oxidation" suddenly becomes "burning", which then proceeds to produce enough heat to maintain the reaction until the supply of oxygen or fuel runs out, or until other influences produce enough cooling effect to quench the fire. It’s perhaps fortunate we have only 21 percent oxygen in our atmosphere, and that 78 percent is made up of nitrogen, which won’t combine with oxygen at any temperature normally reached by the burning of other materials. We don’t often think of it in that way, but the nitrogen acts as a cooling agent. A good part of the energy produced by the burning of carbon and hydrogen in air is used up in heating the nitrogen. In an atmosphere of 100 percent oxygen, burning takes place at a greatly accelerated rate. Given such an atmosphere, a wooden house that caught fire would probably burn flat in a matter of minutes, rather than hours. If there’s one thing you must remember about oxygen, it’s that things burn much faster in pure oxygen (or even in a mixture of half oxygen, half nitrogen) than they do in air. That is why passing a lighted cigarette to a person in an oxygen tent is almost equivalent to signing his death warrant. The other thing you must remember is this: that when surrounded by pure oxygen, some oils and greases oxidize rapidly, fast enough to reach kindling temperature in a short time. That is why you must always keep oxygen away from oils and grease, and keep oil and grease from getting into an oxygen regulator or hose. The only lubricants which can be used with oxy-acetylene apparatus – and then only on threads and O-rings – are special products approved for such use.

Acetylene is a "hydrocarbon", just as are propane, methane, and virtually all the components which make up gasoline and fuel oils. However, it differs from those hydrocarbons in this respect: in the acetylene molecule, made up of two carbon atoms and two hydrogen atoms, the carbon atoms are joined by what chemists call a "triple bond". When acetylene reaches its kindling temperature (and under some other conditions as well, which we’ll cover shortly) the bond breaks and releases energy. Virtually all the acetylene distributed for welding and cutting use is created by allowing calcium carbide, an electric furnace product, to react with water. The triple bond which makes the oxy-acetylene flame the hottest of all gas flames is also responsible for two rather exceptional properties of acetylene gas which you should always remember. The first is this: that free gaseous acetylene, depending on confinement conditions, is potentially unstable at pressures above 15 psig (103kPa). If subject to severe shock, or a source of ignition, some of the triple bonds may break, releasing enough energy to cause all the other molecules in the enclosed volume to decompose into carbon and hydrogen with explosive force. The force of such an explosion is not so great as that released by the explosion of most mixtures of acetylene and oxygen, or acetylene and air, but it is substantial, and can be withstood only by extra-heavy-wall steel tubing [2, 3, 4].

3. HEAT AFFECTED ZONE AFTER CUTTING

In metals with polymorph transformation occur structural changes in HAZ. By determination of phase changes in HAZ after cutting is used scheme of structural zones creation in welded joint. Temperature intervals are derived from Fe – Fe_3C diagram for low carbon steel. If we do not consider area of welded metal microstructure then we can define individual areas of phase transformation for areas obtained by heat cutting

The experiment was realized in the firm Gohr s.r.o. in Spišská Nová Ves. The samples is made from steel ISO Fe510 with various thickness, 10, 15 and 20 mm. The cutting machine was Multitherm 3100 made in firm Messer cutting system. Parameters of cutting were determined automatically by machine software (Table 1).

Criterion for detecting of depth of heat affected zone was microhardness which was measure in the layer 2 mm under surface. Measurement was realizes on three lines of sample, i.e. 2 mm from the edge and in the middle of sample. Results of the measurement by Vickers are showing higher heat affected zone than after cutting with laser or plasma. This heat affected zone is depending on

Table 1

Parameters of cutting process

Thickness	**Thickness 10 mm**	**Thickness 15 mm**	**Thickness 20 mm**
Speed of cutting (mm/min)	561	503	417
Diameter of nozzle (mm)	1.2	1.4	1.4
Pressure of oxygen (bar)	5 ÷7	6÷7	6÷7

thickness of material. In all examples is increasing of microhardness from primary material. Largest accrue was for sample of thickness 15 mm and that was 90 HV1 in average (Fig. 6). For sample with 20 mm thickness it was 70 HV1 in average (Fig. 7) and for thickness 10 mm 60 HV1 (Fig. 5). The high temperature for heating is not so long time and transformation is only half-way. Phase transformation $\alpha \rightarrow \gamma$, melting of carbides and mainly homogenization of austenite are dependence on temperature, on the time of staying on high temperature and on the speed of cooling. Austenitic grain which is rising during high speed heating is finest. When is the heating insufficient, austenite is not homogenized and troostite and ferrite are rising in the structure of steel.

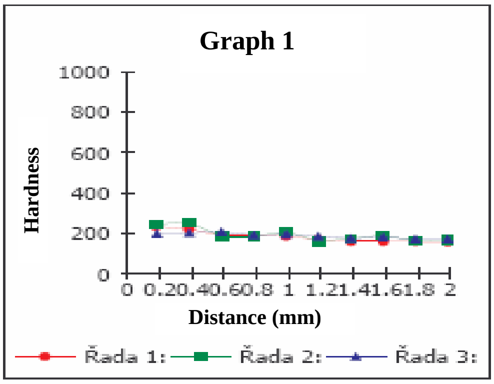

Fig. 5. Microhardness of sample with thickness 10 mm.

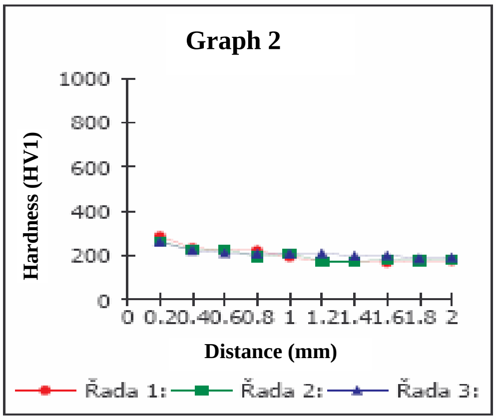

Fig. 6. Microhardness of sample with thickness 15 mm.

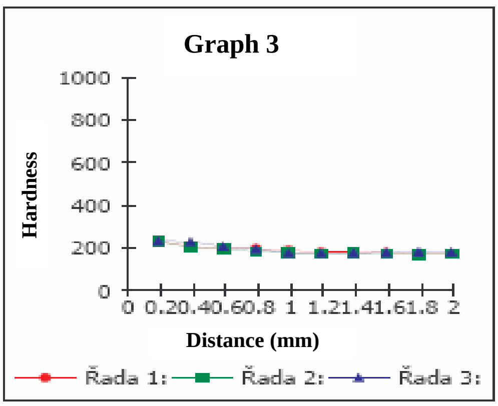

Fig. 7. Microhardness of sample with thickness 20 mm.

Fig. 8. Zone of high heating (zoom 200 x).

Fig. 9. Zone of incomplete recrystallization (zoom 200 x).

After cutting with oxygen is the steel not hardened and heating from cutting process is trivial for structure of steel. Heat affected zone is only near of the cutting surfaces and edges in structure of steel are perlite and sorbite. Sorbitic structure in heat affected zone is not decrease quality of steel. It increases mechanical properties of steel, primarily strength with good steel ductility (Figs. 8 and 9.).

4. CONCLUSIONS

The changes of microstructure of steel after thermal cutting with oxygen are dependence on thickness of material and chemical composition of material. The more is thickness of material bigger, the more is heat affected zone bigger and changes in the structure of steel are extensive. For example, the depth of heat affected zone for sample with thickness 20 mm was 2 mm, for sample with thickness 15 mm was 1.4 mm and for sample with thickness 10 mm was 1 mm under surface.

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