BACK TO THE BASIC......

Thermal Effects of Cutting on Mild and Alloy Steels

E. Seymour Semper

It will be expected that local heating of steel by cutting, particularly with higher carbon steels, will cause hardening on and below the cut surface. Consideration of the principles of the process, however, and metallurgical examination of cut surfaces, show that this hardening effect is less in degree and depth than is probably generally supposed. The heat arises, of course, from the preheat flame and to a greater extent from heat evolved by the reaction between the cutting oxygen and iron. In the result the surface of the cut face is brought to a temperature little below, or in some instances up to, the melting point of the steel.

However, heat input is a matter of time as well as temperature and the cutting stream moves relatively fast; consequently the thermal effect is confined to a narrow band each side of the kerf. This suggests that within the limits of practicability, a small high-speed nozzle and low cutting pressure will, by reducing heat input from the preheat flame and reaction, tend to minimize further thermal effects. This is amply borne out in practice, and again indicates the desirability of working under correct cutting conditions.

Surface hardening after cutting seems to arise from two effects within the steel itself. First, tests on mild and carbon steels have shown what appears to be a tendency for migration of carbon to the cut surface. The surface itself shows an increment of carbon while just below is a narrow decarbonized band. It is thought that carbon may migrate from relatively colder metal to hotter metal. Possibly, too, under some conditions of reaction there may be a pick-up of carbon from metal oxidized in or removed from the kerf. That this surface carbonization cannot be attributed to the preheat flame is proved by the fact that the effect is the same either with coal gas or such a carbon-rich gas as acetylene. Secondly, during cutting, heat is conducted away rapidly from the cut by colder metal alongside, which causes a quenching effect. While this is generally of little consequence when cutting mild and lower carbon steel it becomes more important as the carbon or other hardening elements are increased. The hardening effect is also greater as the thickness of alloy steels being cut increases.

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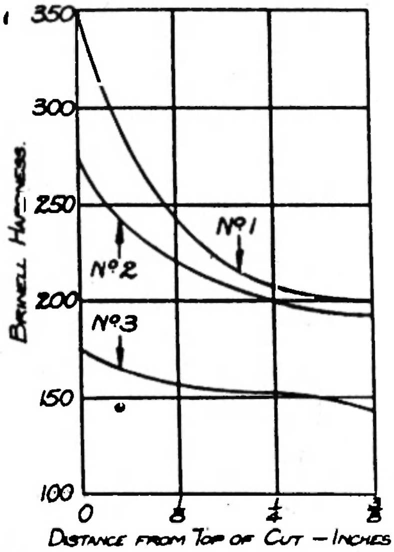
HARDENING EFFECT

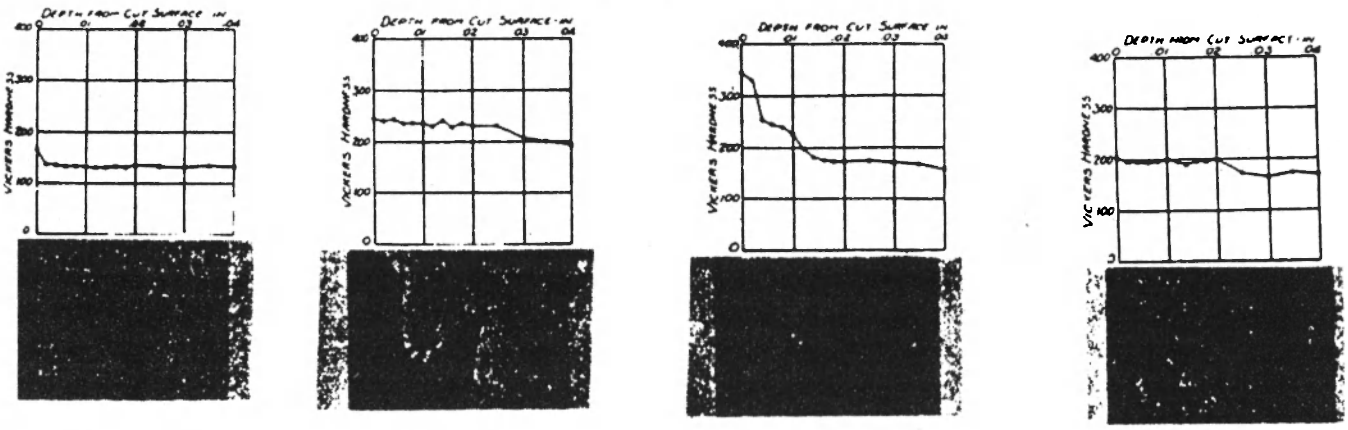
Fig. 1 shows this hardening effect for 6½ -in billets in three qualities of steel. It will be seen that while the hardening is small for 0.28 per cent carbon steel there is appreciable hardening in the medium carbon steel and an even greater increase in hardness in the nickel-carbon steel, although the carbon content is lower than in the straight carbon steel. It is, therefore, necessary to differentiate between mild and low carbon steels and alloy steels.



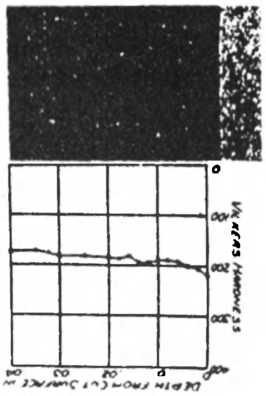
Curve No.	B.S. Tyupe	Composition	Original Hardness
1	EN 21R	.35C 3.5 NI	195
2	EN9	.55C	190
3	5007/216	.28C	140

Fig. 1 : The hardening effect when cutting 6½ in billets in three qualities of steel

(a) MILD STEEL : Tests on mild steel containing up to 0.30 per cent carbon show that for most purposes the physical and chemical effect of cutting on the steel is negligible. A slight toughening of the cut face occurs which does not present machining difficulties since the increase in hardness at the surface is only 30/50 points Brinell, decreasing to normal at a depth up to ⅛ in ☞



Machanised *Sheared* *Friction sawed* *Oxygen cut by hand*



Oxygen cut by machine

Fig. 2 Comparison of the effect of cutting by oxygen and mechanical methods

according to the thickness being cut. Tensile specimens with oxy-cut surfaces show a slight increase in yield point and ultimate strength over mechanically-machined specimens. Bend tests with the oxy-cut surfaces on the tension side usually bend to 180 degrees without any sign of cracking. Several investigators have found that oxygen cutting may have less detrimental effect on the steel at the cut edge than other methods of cutting such as shearing, machining or friction sawing.

Fig. 2, shows a comparison. The cuts were made on ½-in mild steel by the three mechanical methods mentioned and by oxygen cutting by hand and machine. Examination of the microstructure and comparison of the hardness curves shows the damaging effect of shearing and friction sawing; and that, while oxygen cutting gives a slightly higher hardness figure than machining, it induces a toughened sorbitic structure which actually slightly improves the mechanical properties of the steel just below the cut edge.

It should also be noted that the oxygen-cut specimen has a thermally affected zone only about in 1/32 in deep on ½ -in mild steel and that the heat disturbance is slightly less with machine cutting than with hand cutting. While 0.30 per cent is generally regarded as the upper limit of carbon content in which ordinary carbon steel can be cut cold, it should be added that when cutting heavy sections, say over 8 in thick, cracking can occur even with 0.25 carbon steel unless cut warm. Oxygen cutting is accepted as a method of plate-edge preparation for welding by all approving and classifying authorities, for mild steels.

Approval is subject to the following precautions—

(a) The use of automatic controlled machines.

(b) Use of correct cutting conditions.

(c) Mill scale and/or paint should be removed by passing the lighted preheat flame along the cut and then wire brushing.

(d) The oxygen-cut surface to be wire-brushed before welding; and

(e) where an oxygen-cut edge is not entirely removed by a weld or if it has to be bent before welding, the cut edge should first be ground away.

(*b*) CARBON AND ALLOY STEELS : Alloying elements in steel have two possible effects : they may render the steel less amenable to oxygen cutting, or they may increase the hardness of the cut face to such an extent that cracking can occur as the steel cools. With an increased proportion of carbon or other alloys, the steel becomes more responsive to this localized cooling, and it is, therefore, usually desirable to preheat it before cutting.

The main advantages of preheating are—

(1) Preheating increases the efficiency of oxygen cutting and reduces oxygen consumption.

(2) By reducing the temperature gradient below the cut surface, cooling stresses are relieved and distributed.

(3) By reducing the rate of cooling, hardness induced by quick cooling is minimized.

Preheating is preferably done in a muffle furnace, but other means can be used providing the heating is done slowly and evenly. The preheating furnace should be alongside the cutting machine so that time is not lost between removal from the furnace and making the cut. If allowed to stand before cutting, heat will be lost from the surface while the middle is comparatively hot; the oxidation reaction will then proceed more energetically in the middle and thus make a bad cut. The steel should be preheated to about 300°C and a higher preheat temperature than 450°C is likely to lead to overheating and excessive slagging down the kerf, and trouble may be caused by heavy surface scale which will result in bad cutting. Loose surface scale should always be brushed away before commencing to cut. After cutting the steel should be cooled slowly and evenly and away from draughts.

As suggested, it is usually necessary to preheat steels containing over 0.30 per cent carbon (with or without other alloying elements), although small areas or thicknesses of "medium carbon" steel may sometimes be cut cold provided they are in normalized condition.

Much depends on the physical condition of the steel and the purpose for which it is required. For instance, it was found that plates of high tensile steel used in the fabrication of armoured vehicles by welding could usually be cut cold. The thermally affected zone was less than the depth of penetration of the weld and was

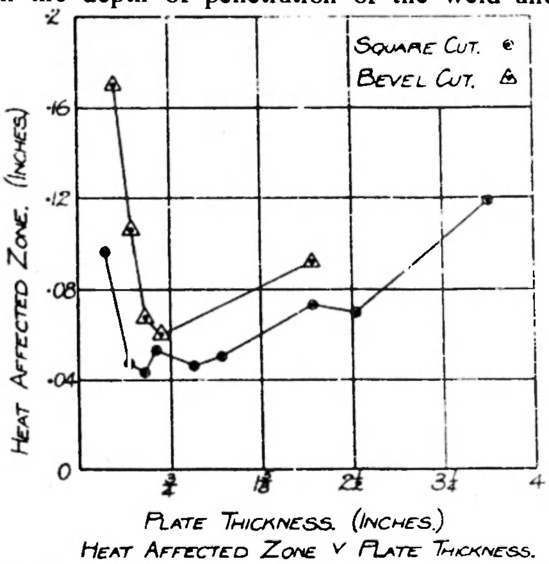


Fig. 3 : Influence of plate thickness on the heat-affected zone in high tensile steel plate

therefore re-melted and absorbed in the weld. It has already been mentioned that plate thickness has some influence on the depth of heat disturbance and Fig. 3 illustrates this. Plates up to 4 in thick in armour quality were used and the curve shows a sharp drop in the disturbed depth from ⅛ in to ¾ in thickness, thereafter rising steadily to a depth of ⅛ in for the 4-in thickness.

EFFECT OF HEAT ON ALLOYING ELEMENT

Another point previously mentioned is illustrated by curves shown in Fig. 4, where cutting speed is plotted against depth of heat disturbance for the same steel. This shows the desirability when cutting an alloy steel cold of working at the highest possible speed of cutting. It should finally be added that an alloy steel of good weld ability is also satisfactory for oxygen cutting.

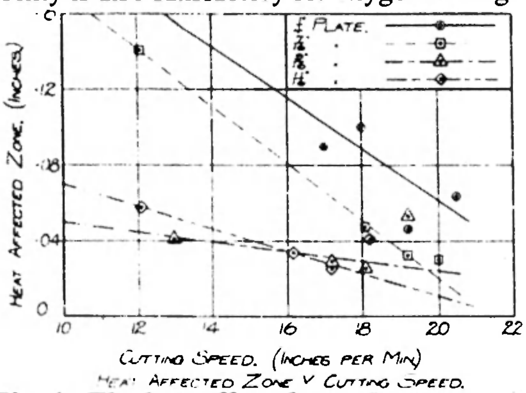


Fig. 4 : The heat affected zone for four thicknesses of high tensile steel plate cut at different speeds

So far we have only referred to the thermal effect of carbon and other alloys used in steel as hardening agents. Alloys also affect the "cutability" of steel.

The following are the main alloys met with and hints are given for dealing with steel containing them —

CARBON : The effect of carbon in steel on the cutting process is hardly noticeable up to the percentage at which preheating becomes desirable. When medium and high carbon steels are preheated the effect of the carbon is not of consequence when cutting.

MANGANESE : Steel containing up to 1.6 per cent manganese should offer no difficulty, but with 12 to 14 per cent manganese steels cutting should be done at the highest possible speed compatible with obtaining a good cut surface and the cut should be cooled as rapidly as possible. A convenient method of softening the cut edge by quenching is to have a jet of water attached to a following the cutter in such a way that it flushes down the kerf.

SILICON in amounts usually present in steel has no effect on the cut, neither has cutting any effect on the steel, except in so far as other elements are usually used in association with silicon.

CHROMIUM : Pure chromium reacts with oxygen to form a refractory and infusible oxide, consequently the difficulty in cutting chromium steels increases with the amount of chromium present. Up to 5 per cent chromium usually gives little or no trouble. Above this and under 10 per cent requires special technique and the cut is rough.

NICKEL : Steels containing up to 7 per cent nickel present no difficulty. A slight drop in cutting speed is desirable and preheating may be necessary. Up to 25 to 30 per cent nickel steels require a special technique.

TUNGSTEN : In the pure state tungsten may cut, but it requires a higher preheat temperature. Alloyed with steel up to 12 to 15 per cent it may be cut fairly readily, but difficulties are experienced above this amount.

SULPHUR and PHOSPHORUS in amounts usually tolerated in steel have no noticeable effect on cutting.

MOLYBDENUM : Although difficult to cut in the pure state, molybdenum as an alloy is not discernable when cutting steel containing the proportion of molybdenum usually used.

COPPER and ALUMINIUM are not usually added to steel in sufficient quantity to affect its oxygen-cutting properties.

VANADIUM : This alloy in small amounts may improve rather than interfere with cutting.

CONCLUSION

Usually rolled alloy steels, particularly those containing chromium, have a fairly heavy scale on the surface, which it is helpful to remove before cutting. This can often be done by passing the preheat flame along the line of cut. Heavier scale may require flame descaling and wire brushing. Sometimes heavy scale may necessitate grinding. If the scale is not removed, a larger preheat flame and lower speed than desirable will be required, resulting in a poor cut with rounded top corners. Generally it will be found that the best results on alloy steels, particularly if chromium is present, are obtained with a slightly higher speed using a smaller nozzle and lower pressure than for the same thickness of mild steel.