14 The steels containing 0.4 per cent antimony, 0.8 per cent or more of copper, or 0.8 per cent arsenic did not have good hot-working properties, illustrated by numerous corner cracks on the bars, while those containing 1.7 per cent antimony or 1.8 per cent tin showed a high degree of hot shortness and could not be forged or rolled. Also the steel with 1.77 per cent copper could itself be machined only with difficulty in the annealed condition.

15 Phosphorus up to about 0.06 per cent and sulphur up to 0.215 per cent did not appear to be injurious, from the viewpoint of lathe-tool performance of the customary chromium-tungsten-vanadium steels, with or without cobalt. However, high sulphur tended to lower the cutting speeds in the presence of $3^{3}/_{4}$ per cent nickel. Because of the possibility of segregation of the phosphorus and the introduction of numerous sulphide inclusions in high sulphur steels, these two elements can advisedly be kept within low limits for all high-speed-steel lathe tools.

16 Aluminum adversely affected the performance of the high-speed-steel tools both with shallow cuts and under heavy duty. It was one of the few metals considered which, in proportions around 0.3 per cent produced a measurable decrease in the cutting speeds in rough turning. This decrease became greater as the proportion of the aluminum was increased, and with 0.8 per cent the drop in cutting speed was greater than that produced by equal proportions of any of the other elements considered. These changes were accompanied by decrease in the hardness of the quenched steels, probably through decrease in the dissolving capacity of the aluminum-iron solid solution for carbon, chromium, tungsten, and vanadium. With 0.8 per cent aluminum there was also evidence of a low-melting eutectic in samples quenched from 2350 deg. fahr.

17 Titanium was another of the elements which appeared to lower the dissolving capacity of the austenite, and as a result the hardness and the cutting speeds of the high-speed-steel tools decreased with increase in the titanium. Its interference was lessened, probably through the formation of less harmful carbides, instead of solution as titanium in the austenite, by increasing the carbon content of the steel.

18 Tantalum did not appear to be promising as a substitute for vanadium or as an alloying element in the customary chromium-tungsten high-speed steels for lathe tools. It acted in a manner similar to aluminum and titanium in that it appeared to decrease the dissolving power of the austenite for the chromium and tungsten compounds and so decreased the hardness and cutting speeds of the quenched lathe tools.

XIII—ACKNOWLEDGMENTS

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Discussion

Orlan W. Boston.[62] Unquestionably the paper furnishes information on the subject of turning with shallow cuts at high speeds which has long been needed. It seems rather unusual that the results of the dynamometer tests to show a relation between vertical or horizontal forces on the tool and the tool life

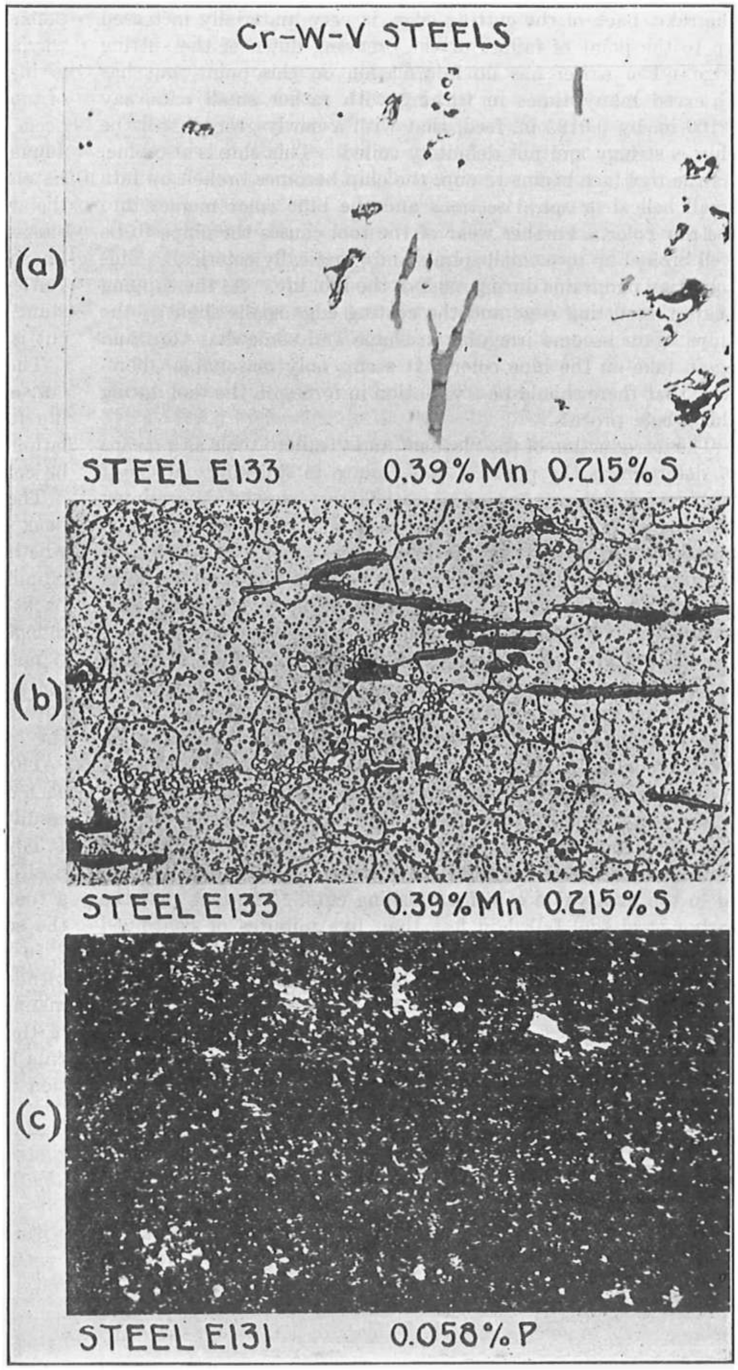

Fig. 42 Structures of Hardened High-Speed Steels Containing High Phosphorus or High Sulphur ×500

(Samples oil quenched from 2350 deg. fahr., not tempered; *a*, unetched; *b*, etched with 5 per cent HNO_3 in alcohol; *c*, etched with Stead's reagent.)

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[62] Professor of Shop Practice, University of Michigan, Ann Arbor, Mich. Mem. A.S.M.E.

were not more decisive. Obviously, during the wear of the tool the shape of the tool is altered. Where a ductile material is cut the tool failure is usually a result of a cupping action which wears gradually toward the cutting edge until the cutting edge is insufficiently supported. During this cupping action the rake, back of the cutting edge, is very materially increased up to the point of failure or the breaking down of the cutting edge. The writer has no information on this point, but has observed many times in turning with rather small cuts, say 0.100 in. by 0.0125 in. feed, that with a newly ground tool the chip is stringy and not definitely coiled. This chip is also blue. As the tool face begins to cup, the chip becomes broken up into small helical or spiral sections and the blue color merges into a straw color. Further wear of the tool causes the chips to be well broken up into small spirals and practically colorless. This condition maintains during most of the tool life. As the cupping nears the cutting edge and the cutting edge spalls slightly, the chips again become irregular in shape and somewhat torn and again take on the blue color. It seems only reasonable, therefore, that there should be a variation in forces on the tool during this whole process.

The introduction of the "leader" and "trailer" tools as a means of determining the point of tool failure in finishing cuts is of considerable importance, as no satisfactory way of determining the time of failure has previously been reported. The question may be asked as to why the broad-nosed tool was selected as the form for the best tool. This form does not seem to be of general use commercially. The results, however, would apparently not be altered by the use of this shape, as the other tool shapes give similar but slightly different values.

The results showing the effect of cutting speed on tool life show some variation in the exponent of the equation $VT_n = c$. The writer wonders if this variation is not due to the actual cutting condition rather than to experimental error; that is, is there not a gradual merging of the value of the exponent from $^1/_7$ for roughing cuts to $^1/_{12}$ for finishing cuts, and if so, what is the nature of this merging curve, and how is it influenced by depth and feed? There still appears to be some question as to the final value of n for finishing cuts. The fact that the carbon-steel tool failed in less than five minutes or continued to cut for 90 or more minutes without sign of failure is again a matter which should be explained further.

It is perhaps unfortunate that the authors did not carry out their experiments a little further with a view to establishing the laws of cutting with particular reference to the influence of the depth and feed which make up the cross-sectional area of the chip. Apparently not much greater experimental work would have been needed. This question is continually raised. Taylor's work, in spite of its age, is still one of the leading forces tending to show the influence of each of the variables rather than their product. This point has been discussed very competently by George Kiebel, M.E., of the Eastern Chinese Railway,at Harbin, in a paper, "Diagrams for Metal Turning Lathes," giving a precise method of the most advantageous utilization of tool and lathe as reported to a technical meeting of the Engineers Locomotive Society of the Chinese Eastern Railway on January 5, 1929. In this paper Mr. Kiebel lays great emphasis on the independent use of the depth and feed, rather than the area of cut. It is known that thick chips are removed more efficiently considering power than thin ones, and yet it is also known, as pointed out under the conclusions of Ripper and Burley, on the seventh page, that if the area of cut is kept constant, a higher associated cutting speed is obtainable when the cut is deep and the feed fine.

The authors' conclusions as to the effect of feed, depth of cut, and area of cut on the cutting speed for a 90-minute tool life for carbon-steel tools are extremely interesting. The relation of these curves to those for high-speed steel tools should be continued for smaller cuts.

The authors' conclusions as to the influence on tool life of back and side slope are also interesting. It is not clear, however, whether it is meant that the tool having the greatest speed for 90-minute tool life is one having 0-deg. side slope and 30-deg. back slope or whether these optimum angles were determined independently. If they were determined independently, might it not be possible that their combination might not yield the optimum results? The power would be lowered still further with an increase in the true rake, so it must be concluded that the "power" and "tool-life" factors of a tool are not in agreement.

The investigation on the influence of a coolant, representing each of the three general classes, corresponds in general with the results previously reported by the authors for rough cutting. It is unfortunate that further work was not done to determine positively the influence of the coolants on the cutting speed for a tool life greater than 50 minutes. This undoubtedly will be the subject of further investigation.

In general, the writer feels that the authors are to be commended on the thoroughness of their investigation and the clear manner in which their results are presented. Certainly, many of the points about metal cutting under the conditions of fine cuts have been cleared up and a great deal of definite information has been added to the long story of metal cutting.