up to 500 °C (932 °F) or with burners. The simplest method is to move the burner backwards or downwards over the area to be hardened before starting the hardening pass. It is, however, possible to have one or several preheating burners precede the hardening burner. Sometimes it is advisable to impart to the preheating burner an oscillating movement in the direction of the feed. By this method a much higher preheating temperature may be chosen under certain conditions even a temperature higher than the actual hardening temperature may be used. Fig. 52 shows an example.

e) Operating methods. From the above it can be seen that the maximum attainable case depth is generally larger for the total surface hardening method than for the progressive hardening method as heating speed, equalization time, and quenching speed can be more easily varied and inside wider limits.

53. Attainable case depths. The above investigations show that the attainable case depth depends on the critical diameter of the material, on the dimensions of the workpiece, and on the operating conditions. Table 8 gives the attainable case depths for different materials under ordinary operating conditions. However, it should be pointed out that the wall thickness must be at least 3 to 4 times larger than the desired case depth. From this it appears that the smallest diameter that can be hardened is about 15 to 20 mm (0.59"...0.78"). For shallow case depth and smaller diameters the special steel RBH should be used. Plain carbon steels take a maximum case depth of about 4 mm (0.16"). For deeper case alloy steel must be specified. With increased alloy content the case depth can be increased as required. It is, however, important to notice that an increased case depth increases the hardening time only slightly in contrast to case hardening.

IV. Actual flame hardening

A. Design of the workpiece

54. Specifications on drawings. Flame hardening requires careful preparations in the design department. The designer must get familiar with the hardening methods their peculiarities and possibilities in order to specify practical and easily understood instructions. Furthermore he should consult the hardening department in order to take advantage of its experience when designing a part to be hardened. Clear specifications on the drawing help to avoid misunderstandings between design and hardening departments and prevent mistakes in hardening and scrap. As standards so far have not yet been established the following is suggested:

a) Hardness pattern. On each drawing of a part to be hardened the hardness pattern shall be shown on several views in the lower left hand corner if necessary in reduced scale. Details of no importance for hardening shall be omitted, but fillets, radii, bores etc. if important for hardening must be shown. As the hardness pattern is part of the finished product the data given should refer to the final state of the part.
h) Specifications for the required surface hardness. Due to the specified material only a limited hardness degree is attainable (see paragraph 42). The required surface hardness shall always be given with a sufficient tolerance, e.g. $58 \pm 2$ RC or $58$ RC minimum. The location where the hardness should be tested shall be indicated by an arrow. The hardness degree shall be given in units of the desired testing method, for flame hardening usually Rockwell C.

c) Case depth. There is no agreement yet on the definition of case depth. The following definitions are in use:

1. According to Material Sheet 830-55 of VDEh case depth is defined as the depth of the outer layer of a hardened workpiece where a certain hardness degree still exists. This minimum hardness is for
   - steels with a C content larger than $0.42\% = 50$ RC
   - steels with a C content smaller than $0.41\% = 45$ RC
In the literature other definitions are often used.

2. The case depth is the depth where a certain percentage of the hardness of the outer layer or of the required hardness still exists usually 95 to 85%.

3. The case depth is the depth where the grain structure still contains 50% martensite.

Definition 1 favors materials with high carbon content. Definition 3 requires metallographic polished sections or a careful analysis of the carbon content. The author therefore prefers definition 2 wherein a value of 90% for flame hardening comes close to most requirements of operating conditions.

The case depth should be given in such a way that to produce it a plus tolerance of 50% of the specified depth could be used. For instance

\[1.5 \text{ mm} (0.06\text{”) specified case depth} + 0.75 \text{ mm} (0.03\text{”) tolerance} = 2.25 \text{ mm} (0.09\text{”) theoretical case depth after hardening.}\]

As the grinding tolerance has to be deducted from this value the actual tolerance is considerably smaller.

The case depth can only be measured on a polished fracture. Non-destructive methods are being explored but so far have not given reliable results in all instances.

55. Finishing allowances. The designer must furthermore provide sufficient allowances for machining. By rolling and forging the surface is considerably decarburized. The machining allowance should therefore be not less than 2 to 3 mm ($0.0785\text{”}...0.118\text{”) to bring the sound and uniform material to the surface. As on cold drawn materials such surface decarburization can be found up to a depth of 0.5 mm ($0.0197\text{”) the required minimum hardness has to be reduced or the piece has to be machined as the otherwise attainable surface hardness of the material cannot be produced.

Allowances for grinding can generally be kept smaller than for case hardening. In consideration of the distortion the case depth should not be specified too deep. A grinding allowance of maximum 0.5 mm ($0.0197\text{”) is usually sufficient, in many instances it can be reduced to 0.1 mm ($0.0039\text{”)}. Removing the case by grinding is therefore not to be feared as for case hardened pieces, as in flame hardening the case depth is alway deeper than the distortion.

56. Bearing clearance. A sufficient bearing clearance must be provided if the flame hardened case is to withstand continuous operation. On crankshafts and lathe spindles which obviously require a clearance of less than 0.01 mm ($0.0004\text{”) destruction of the flame hardened case has occasionally been observed because the bearing was overheated due to insufficient lubrication. Where the bearing clearance cannot be increased due to the required accuracy a sufficient and reliable lubrication has to be assured as only then do flame hardened parts live up to all requirements.