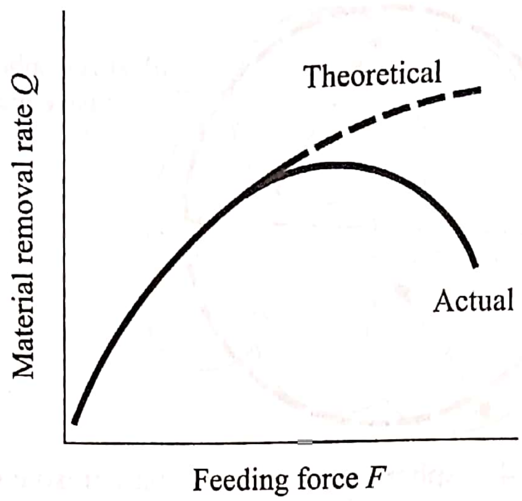


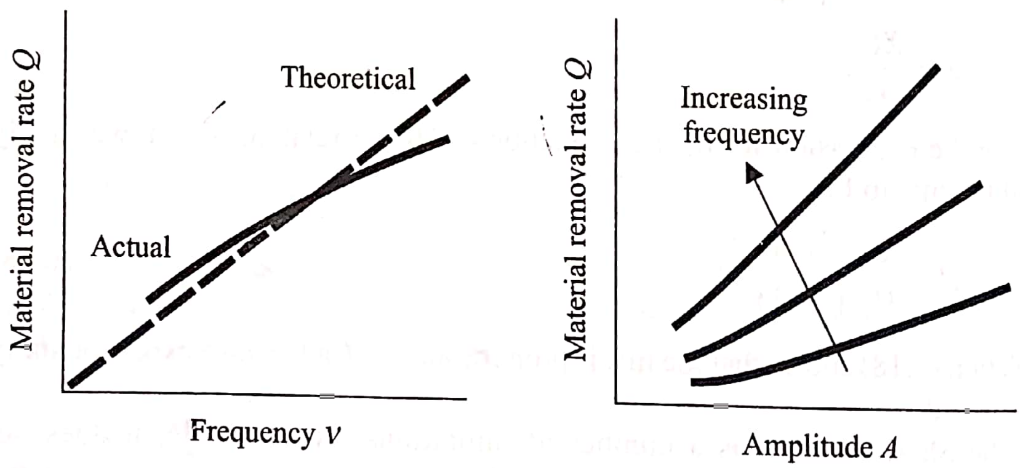
Fig. 6.15 Variation of material removal rate with feed force.

(iv) hardness ratio of the tool and the workpiece,

(v) grain size,

(vi) concentration of abrasive in the slurry.

(i) As can be seen from relation (6.18), the mrr increases linearly with the frequency. In practice also, the mrr increases with the frequency (see Fig. 6.16a) but the actual characteristic is not exactly linear. The mrr tends to be somewhat lower than the theoretically-predicted value.



(a) Variation with frequency (b) Variation with amplitude

Fig. 6.16 Material removal rate characteristics in USM.

(ii) When the amplitude of vibration is increased, the mrr is expected to increase, as can be seen from relation (6.18). The actual nature of the variation is as shown in Fig. 6.16b for different values of the frequency. Again, the actual characteristic is somewhat different from the theoretically-predicted one. The main source of discrepancy stems from the fact that we calculated the duration of penetration Δt by considering the average velocity ($=A/(T/4)$). The characteristic of variation of Δt, given by

$$\frac{1}{\nu}\left[\frac{1}{4} - \frac{1}{2\pi}\sin^{-1}\left(1 - \frac{h}{A}\right)\right],$$

is quite different from that obtained from the approximate expression, *i.e.*, $(h/A)(T/4)$.

(iii) We have already said that with an increase in static loading (*i.e.*, the feed force), the mrr tends to increase. However, in practice, it tends to decrease beyond a certain critical value of the force as the grains start getting crushed. The nature of variation of the mrr with the feed force (for various amplitudes) is shown in Fig. 6.17a.

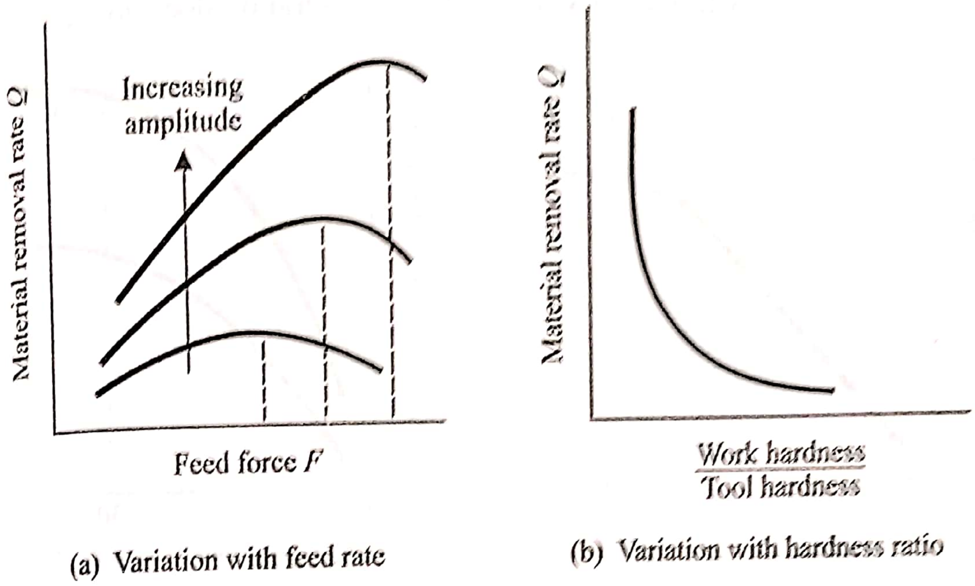


Fig. 6.17 Material removal rate characteristics in USM.

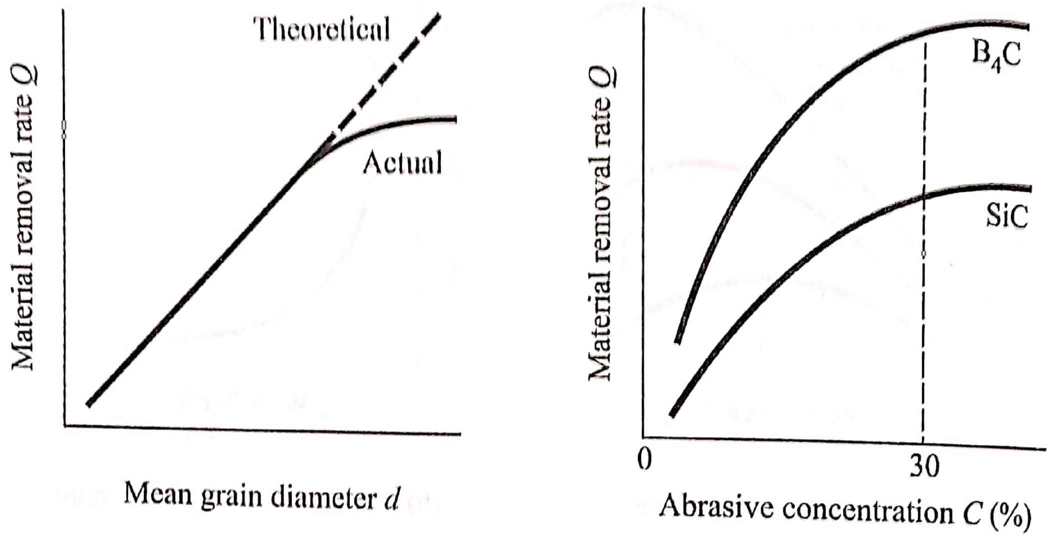
(iv) The ratio of the workpiece hardness and the tool hardness affects the mrr quite significantly, and the characteristic is as shown in Fig. 6.17b. Apart from the hardness, the brittleness of the work material plays a very dominant role. Table 6.2 indicates the relative material removal rates for different work materials, keeping the other parameters the same. Clearly, a more brittle material is machined more rapidly.

Table 6.2 Relative material removal rates (ν = 16.3 kHz, A = 12.5 μm, grain size = 100 mesh)

Work material	Relative removal rate
Glass	100.0
Brass	6.6
Tungsten	4.8
Titanium	4.0
Steel	3.9
Chrome steel	1.4

(v) Relation (6.18) indicates that the mrr should rise proportionately with the mean grain diameter d. However, when d becomes too large and approaches the magnitude of the amplitude A, the crushing tendency increases, resulting in a fall in the mrr as shown in Fig. 6.18a.

(vi) Since the concentration directly controls the number of grains producing impact per cycle and also the magnitude of each impact, the mrr is expected to depend on C. But relation (6.18) shows that the mrr is expected to be proportional to $C^{1/4}$. The actual variation is shown in Fig. 6.18b for B_4C and SiC abrasives. This is in a fairly good agreement with the theoretical prediction. Since the mrr increases as $C^{1/4}$, the increase in the mrr is quite low after C has crossed 30%. Thus, a further increase in the concentration does not help.



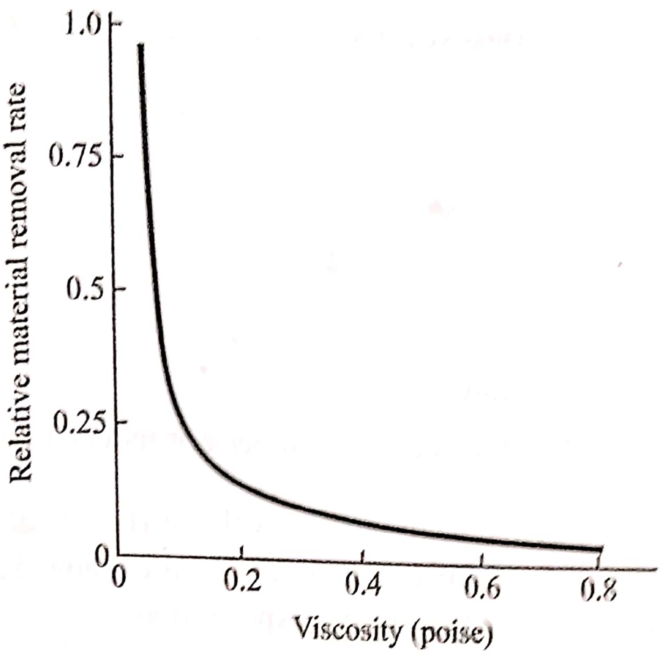
(a) Variation with grain diameter (b) Variation with concentration

Fig. 6.18 Material removal rate characteristics in USM.

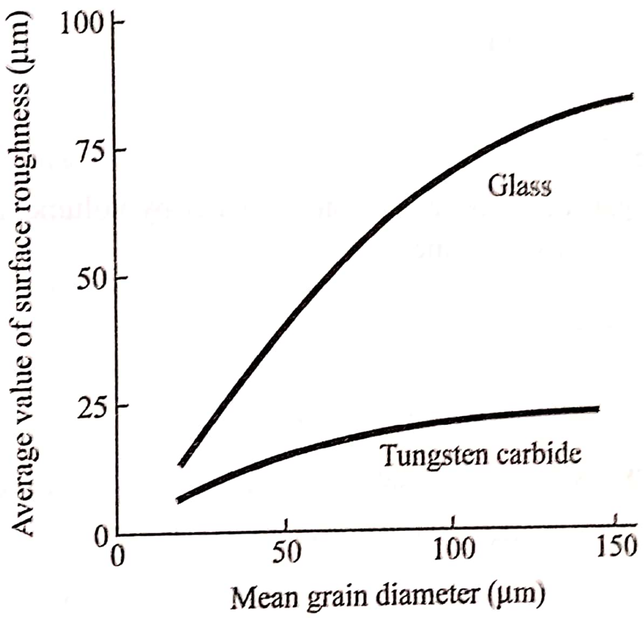
Apart from the foregoing process parameters, some physical properties (e.g., viscosity) of the fluid used for the slurry also affect the mrr. Experiments show that the mrr drops as the viscosity increases (Fig. 6.19a).

Though the mrr is a very important consideration for judging the performance of an USM operation, the quality of finish obtained has also to be considered for a proper evaluation. In an USM operation, the surface finish depends mainly on the size of the abrasive grains. Figure 6.19b shows a typical variation of the mean value of the surface unevenness with the mean grain size for both glass and tungsten carbide as the work material. It is clear that the surface finish is much more sensitive to the grain size in the case of glass. This is because of the fact that, for a high hardness, the size of the fragments dislodged through a brittle fracture does not depend much on the size of the impacting particles.

EXAMPLE 6.1 Find out the approximate time required to machine a square hole (5 mm × 5 mm) in a tungsten carbide plate of thickness 4 mm. The abrasive grains are of 0.01 mm diameter. The feeding is done with a constant force of 3.5 N. The amplitude of tool oscillation is about 25 μm, the frequency being 25



(a) Variation of mrr with viscosity



(b) Dependence of surface finish on grain size

Fig. 6.19 Dependence of material removal rate on viscosity and effect of grain size on surface finish.

kHz. The fracture hardness of WC can be approximately taken as 6900 N/mm^2. The slurry contains 1 part of abrasive to about 1 part of water.

SOLUTION Since relation (6.18) yields only a qualitative result, let us first find out an approximate expression giving the mrr in terms of the other quantities. To do this, let us assume that the volume removed per grit indentation