The dependence of removal rate on dielectric viscosity in EDM

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THE DEPENDENCE OF REMOVAL RATE ON DIELECTRIC VISCOSITY IN EDM

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Introduction

The dielectric liquid in electric discharge machining assumes several distinct roles: first, it acts as the medium for igniting the electrical discharges according to a mechanism which is governed by statistical laws and which is strongly dependent on the liquid composition (1), secondly, it produces, as a thermo-hydrodynamic response to the spark, an ablation process of electrode matter, in particular on the work piece, and thirdly, it conveys the part of the dissipated electrical energy which has not been consumed in the erosive process away from the machining area. All these functions of the dielectric liquid depend in one way or another on its viscous properties.

The viscosity of the dielectric liquid is, therefore, a parameter whose value has an incidence on machining efficiency and, as a consequence, should be chosen with full knowledge of the facts. Since the choice of a less or more viscous liquid has opposite effects on machining efficiency according to which one of the above mentioned different functions of the dielectric liquid we consider, a compromise must be realized in order to optimize the overall behaviour.

The literature on electro-discharge machining is not very abundant concerning the subject of how the viscosity of the dielectric liquid acts on material removal. There are some hints which point to the fact that high viscosity liquids increase the efficiency of machining (2); but a clear vision of how the different functions of the dielectric liquid interfere is lacking.

By taking adequate experimental precautions in measuring the material removal rate we have made an effort to eliminate the influence of flushing as well as that of the variable kinds and rates of discharges. The experimental work on a large variety of hydrocarbon oils is, however, limited to one couple of electrode materials: copper as tool electrode and steel as work piece electrode; this pair being representative for a large number of applications in EDM. The reason of the limitation to one couple of electrode materials is that we first aimed at evaluating the extent to which high viscosity dielectric liquids would be of interest in EDM practice.

Empirical work has shown a long time ago, of course, that no miracles should be expected. But the question has received new actuality in the light of the technique of artificial contamination of dielectric liquids (1). The main reason why practitioners of EDM use low viscosity liquids is linked to
flushing considerations. With artificial contamination it has become possible to run discharges at a larger gap distance between the tool electrode and the work piece electrode than before. As a consequence of working with large gaps flushing of the work area is considerably better and does no more place the same constraints as before on the viscosity of dielectric liquids.

The measurement of the dependence of removal rate on viscosity

The measurements have been carried out on a Charmilles D10 spark erosion machine equipped with a pulse generator P80. Cylindrical electrodes having a diameter of 20 mm with a central injection hole in the tool electrode, made of electrolytic copper, provide an ideal flow geometry for the dielectric liquid. The work piece electrode is composed of VEW K107 steel. Flow velocity and discharge parameters are chosen so that the average value of the pulsed current is maximum and constant for each series of measurements with the various dielectric liquids which have been chosen in the experiment.

The dielectric liquids are composed of paraffinic and naphtenic hydrocarbons. Commercially available products and their mixtures cover the cinematic viscosity range of 1.7 to 45 cSt, referred to room temperature (BP 180 1.7 cSt, Chevron 1 4.3 cSt, FluxElf2 6.5 cSt, BP 200T 2.9 cSt, BP WM2 31 cSt, BP WM6 235 cSt). Since the viscosity of a liquid is temperature dependent it is necessary to know the actual temperature of the dielectric liquid in the area where the discharges occur. Assuming that the temperature of the liquid is close to that of the electrodes, in particular that of the copper electrode being a good conductor, we refer our measurements to the viscosity at this temperature. It amounts roughly to 80°C.

The results of the measurements are shown in Fig. 1 for 4 different power levels \( i_0 \) and several different discharge pulse durations \( t_0 \). Although the data contain a considerable amount of scatter the shape of the curves are all very similar: the material removal rate at the steel electrode increases with growing viscosity of the dielectric liquid. A saturation value is reached above 4 cSt, corresponding approximatively to a liquid of 30 cSt at room temperature. The curves with the highest removal rate for a given power input show invariably, at a viscosity of 1 cSt, a loss of some 30 % with respect to the saturation value.

Common commercial dielectric fluids, having a room temperature coefficient of viscosity of 4 to 6 cSt, remain only 10 to 15 % below maximum performance. A small difference of this order is no incentive to do better. Clearly, the game is not worth the candle. This is only too true insomuch as the rate of wear of the copper electrode increases with increasing viscosity as well; it does so, as a matter of fact, even more rapidly.

Models of a dielectric viscosity dependent erosion mechanism

The result may nevertheless be analysed from the point of view of its scientific aspects. An acceptable model of the erosion
process must be able to account for the observed dielectric viscosity dependence. From the beginning it has been noticed that spark erosion is essentially a thermal process. Many are those who have solved the heat flow equations under various boundary conditions. Such an approach can obviously not explain a dependence on the viscosity of the dielectric liquid. The first question which must be answered should be: which mechanism is responsible for metal ejection?

A realistic hypothesis by van Dijck puts forward explosive boiling of the superheated metal at the instant corresponding to the end of the discharge current pulse (3). To test the hypothesis we examined a laser pulse simulation of the electrical discharge process (4). We applied laser pulses of the same spot size and energy density on a metal surface via a thin liquid layer, the latter being bound by a glass plate. The thin liquid layer is to be considered as being the equivalent of the dielectric liquid in spark erosion. The result demonstrates the striking similarity of the two processes inasmuch as the presence of the liquid layer enhances laser abrasion almost tenfold.

A theory, put forward by von Allmen, to explain laser abrasion advocates the idea that the liquified metal is ejected continuously due to the metal evaporation pressure (5). The good agreement between the pressure piston model of von Allmen and the laser experiments forms an excellent basis for modeling the erosion mechanism of electrical discharges. The theory is superior in comparison with the explosive boiling hypothesis since the latter does not account for the experimentally verified high plasma pressure during the discharge. It also explains the viscosity effect as being caused by the inertial confinement due to the dielectric liquid. The latter gives way to the vapour pressure in the discharge channel according to its flow characteristics which are determined by the coefficient of viscosity. The higher the viscosity the higher remains the pressure and the more efficient will be the process of metal ejection.

References

(1) Frei C., New methods of conditioning the dielectric liquid in EDM, companion paper in the Proceedings of ISEM X (1992)


Figure 1: Material removal rate as a function of the coefficient of viscosity of various dielectric liquids. The room temperature coefficients of viscosity of these liquids are: BP 180: 1.7 cSt; Chevron 1: 4.3 cSt; FluxElf 2: 6.5 cSt; 34% BP 200T + 66% BP WM2: 10 cSt; 20% BP 200T + 80% BP WM2: 14.5 cSt; 5% BP 200T + 95% BP WM2: 25 cSt; 70% BP WM2 + 30% BP WM6: 45 cSt.