Rheological Behaviour of Fluids Used in Hybrid Non-Conventional Technologies

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*Nonconventional hybrid technologies represent a new way for machine construction field and this is the reason for many researches concerning the technological parameters. The dielectric liquids are the carrying agent for the EDMUS (**E**lectrical **D**ischarge **M**achining and **U**ltrasonic **M**achining) technologies and the liquid properties determine the technological performances of the new technical processes. Rheological tests do not emphasize any important differences of the rheological parameters in the experimental field of stress and temperatures ranges. This fact recommends the use of dielectric liquids for a long time without negative effects on the technological processes.*

Keywords: hybrid, nonconventional machining, fluid, rheological behaviour

On the whole manufacturing process, the weight of the non-conventional technologies is continuously growing and diversifying. If in the second half of the 20th century individual non-conventional technology was predominant in the electroerosion, electrochemical and chemical manufacturing, laser as well as in the electron and ions fascicle usage together with the ultrasonic manufacturing, nowadays a new systemic approach is encountered which implies new manufacturing processes and corresponding technological equipment. Among the new recent approaching the superposing of several non-conventional technologies leading to the hybrid non-conventional technologies [1,2] deserves mention. The EDMUS equipment (**E**lectrical **D**ischarge **M**achining and **U**ltrasonic **M**achining) represents one of the manufacturing processes where the electroerosion manufacturing technologies effects and the ultrasonic oscillation manufacturing are superposed.

Experimental part

Testing equipment and method

The equipment in figure 1 was made at „Gh. Asachi" Technical University of Iasi [3] and, as can be noticed, two

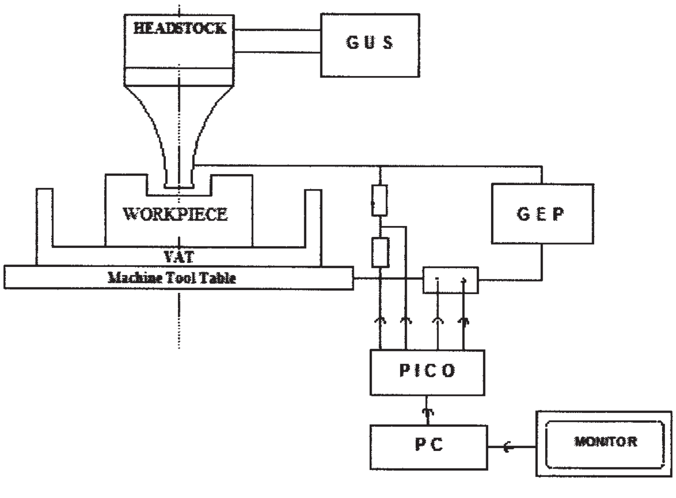

Fig. 1 Technological equipment for the EDMUS non-conventional technology: (GUS-ultrasonic generator, GEP-isoenergetic impulse generator, PICO-oscilloscope)

types of working energies coming from the GUS-ultrasonic oscillation generator and from the GEP-tension impulse generator of rectangular shape are used at the working head. The working head has a tool electrode which will interact with the workpiece electrode fixed on the machine tool table. In the scheme the existence of the tank containing the dielectric liquid, representing the working environment in the hybrid non-conventional technology case can be noticed.

The working environment, i.e. diesel oil, is the headquarter of the complex phenomena which lead to an action against the workpiece and finally to the surface generation. In the EDMUS process case, in the fluid environment plasma channels are developed where electric discharges will be produced and the zone will be influenced by the ultrasonic oscillation as a part of the hybrid manufacturing process.

The rheological behaviour of the dielectric liquid has a great importance in developing the manufacturing process, the influence being played-off in the functional stability of the technological system. An important condition in this case is the fluid flow model maintaining of the liquid on the whole dielectric using process, proved by the rheological parameters stability both for the fresh and the used liquids,. This paper presents the rheological test results obtained for stationary and oscillating shearing regimes for the dielectric liquid in different stages of usage, and it emphasizes the influence of both temperature and the quality of dielectric liquid upon the flow characteristics.

The measurements in the dynamic regime offer more complete information than in the stationary regime, especially regarding the viscoelastic behaviour of the materials, generally, and the multiphase systems, particularly, in relation with the structure of the systems. The stress of the material under oscillating shearing conditions also corresponds to the situation in which the liquid is used.

The working dielectric liquid is submitted to a variable stress, the flow in the working area being more like an oscillating flow rather than a stationary shearing regime.

The rheological parameters in this case are: the complex shear modulus components (storage modulus (elastic) G' and loss modulus (viscous) G''), complex viscosity (η^*) and loss modulus (tg δ) [4].

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The curves G'(ω) and G"(ω) shapes can be very different as functions of the material characteristics and the independent variable ranges (frequency, stress, time) measured by the apparatus [5] .

The experimental runs have been made in the Rheology Laboratory of the Interdisciplinary Training and Research Platform "High Performance Multifunctional Polymeric Materials for Medicine, Pharmacy, Microelectronics, Energy/Information Storage, Environmental Protection in the Natural and Synthetic Polymers Department of the "Gh.Asachi" Technical University of Iasi.

The measurements have been made on an Anton Paar, Physica MCR 501 modular rheometer provided with a CTD 600 system for the temperature control. The measurements have been made with a plane-plane geometry. The higher and lower plates are made of stainless steel. Higher plates of 25 mm diameter have been used.

The apparatus is equipped with a thermosetting system consisting of a CTD-600 convection oven, a TC-30 monitoring and temperature control unit, an EVU liquid nitrogen container and evaporator, assuring the operation process within the -150°C - 600 °C temperature range. The rheometer has a Toolmaster™ system for an automatic identification and configuration, an intelligent configuration system which performs an automatic transfer of the parameters of the measuring system (constructive characteristics, operating constants, geometry) and temperature control to the RheoPlus program. The chip integrated into the geometry contains all the data connected to this program and transfers them automatically to the program. The data corresponding to the accessories are initialized in the program by means of the SmartLink. In this way, the gap between geometries can be supervised and ordered by means of an induction method which estimates its precise size, thus avoiding the errors caused by the normal force or by the thermal extension. The apparatus is provided with bearings on air cushion giving a great sensitivity to it within the domain of small and very small stresses. In addition, all the analyses can be made under conditions of normal force control. The apparatus can operate in both CSR (constant shear rate) and CSS (constant shear stress) modules as well as in DSO (oscillatory dynamic deformation) one, the passing from an operational mode to another being made within second fractions which allows a great flexibility in running specific tests, rotational and oscillatory tests.

Tests have been run in the oscillation regime (amplitude sweep and frequency sweep). With the amplitude sweep (AS) the runs have been made over a deformation domain between 0.01 and 100 %, at an angular frequency ω = 10 rad/sec. The frequency sweeps have been performed within an angular frequency domain between 500 and 0.01 rad/sec, at deformation amplitude between 0.1 and 1% depending on the bounds of the viscoelasticity domain settled for every sample. The used device scheme is shown in figure 2.

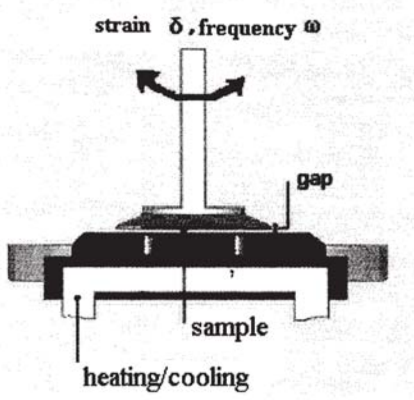

Fig. 2. Scheme of the plane-plane device used for rheological studies

Results and discussions

The flow curves for the fresh and used dielectric liquid (after 50 h of machine running), at three appropriate temperature close to the machine tool working regime – 20, 30 and 40°C, respectively, allow the determination of the temperature influence and of the utilization time interval upon the rheological behaviour of the dielectric liquid.

It is important to know if modification of the flow regime of the dielectric liquid arise after the operating time interval, because the liquid is impure having manufactured particles obtained during the process, a suspension of less or higher concentration being thus obtained. In figure 3 the flow

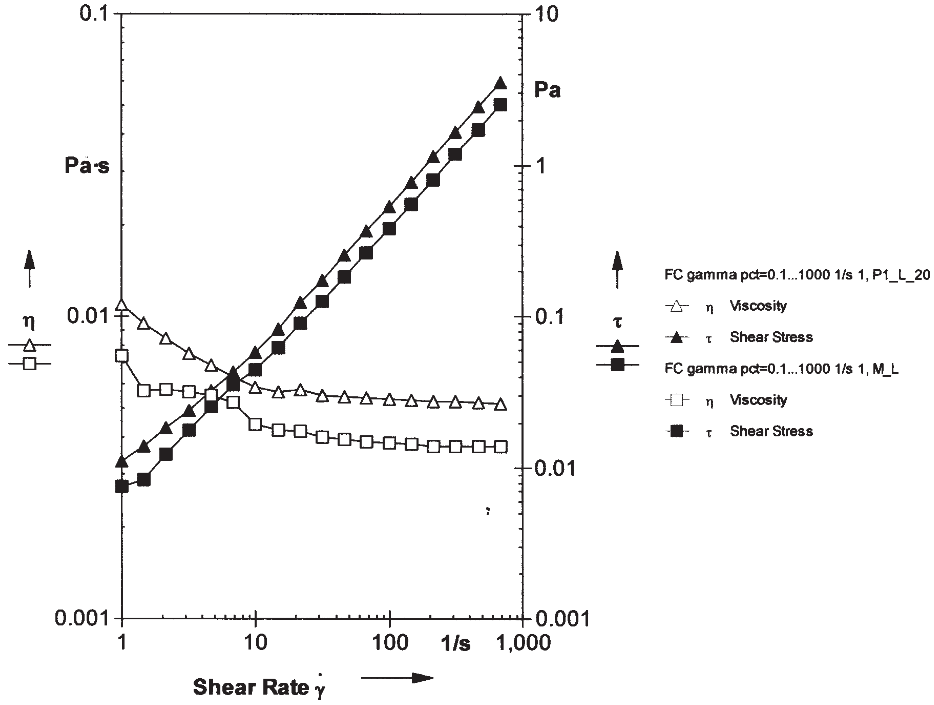

Fig. 3 Rheological functions $\tau=f(\dot{\gamma})$ (bold symbols) and $\eta=f(\dot{\gamma})$ for the fresh liquid (□) and the used liquid (Δ), respectively, at 20°C

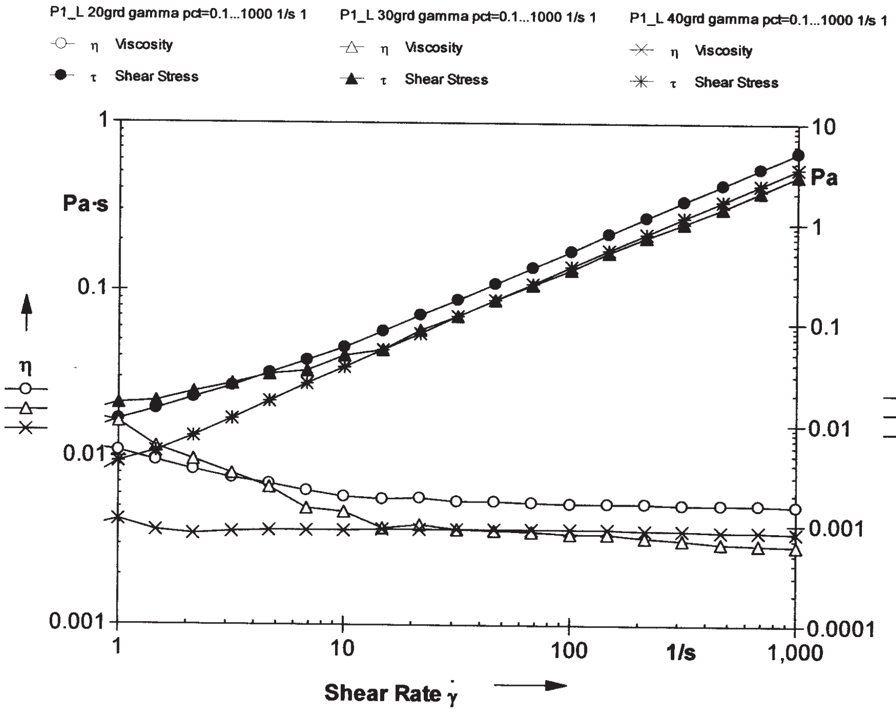

Fig. 4 Influence of the temperature on the flow curves $\tau=f(\dot{\gamma})$ (bold symbols) and $\eta=f(\dot{\gamma})$ of the used dielectric liquid

curves and viscosity variation curves have been plotted, at 20°C, for fresh and used dielectric liquids, respectively. One observes that the curve shapes are very different for the two samples, the viscosity for the used probe being, as expected, higher than the viscosity of the fresh liquid. The rheological profile is not essentially modified, the pseudoplastic domain being maintained for both samples until the shear rate of $20 s^{-1}$, over this value the flow becomes Newtonian. The viscosity modifications in the used dielectric liquid could be appreciated as not significant, thus one can conclude that the flow conditions will not be changed in the working zone.

The rheological profiles for the two liquids, at the three working temperatures (20, 30 and 40°C), lead to the conclusion that the temperature influence is small in this domain, without major influences on the process. In the case of the used liquid (fig. 4), which is a non-homogenous system and thus more sensitive at the flow parameters modifications, the increase of the temperature leads to a viscosity decrease only at temperatures over 20°C and up to 30°C, the curves corresponding to the temperatures of 30 and 40°C being almost identical in the shear rate over $10 s^{-1}$. It is interesting to see that, at the temperature of 40°C, the used dielectric liquid is Newtonian over the whole domain of shear rate and the viscosity remains constant at 4.10^{-3} Pa.s.

The rheological study of the two liquids in the dynamic regime permitted both the behaviour determination at different frequencies and amplitudes as well as the comparison of the two viscosities, namely the shear viscosity and complex viscosity. One must emphasize that the viscous component (G”) of the complex modulus is significant in this case because the Newtonian behaviour of the samples [6].

Figure 5 represents the loss modulus (viscous) G” and the complex viscosity η* as a function of the oscillation frequency ω, at two different values of the oscillation amplitude (deformation) γ= 5% and 10%. As can be seen, all representations are in a narrow domain of values, both the amplitude of the oscillation and the liquid composition

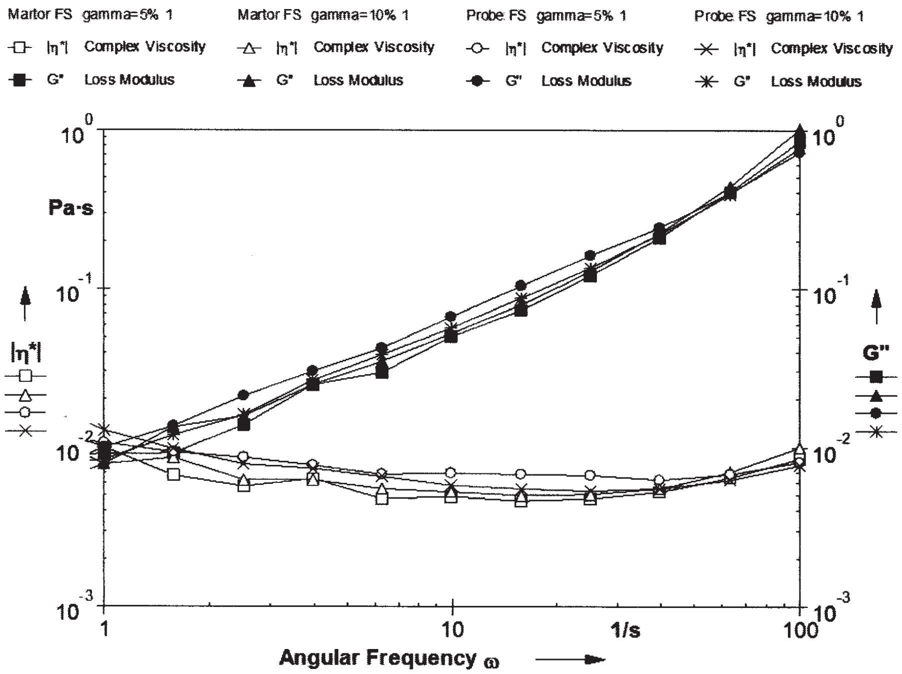

Fig. 5 The variation of the viscous modulus G” and complex viscosity η* as a function of the oscillation frequency for the fresh dielectric liquid (Martor) and for the used dielectric liquid (Probe), by using two different values for the oscillation amplitude (γ): 5% and 10%

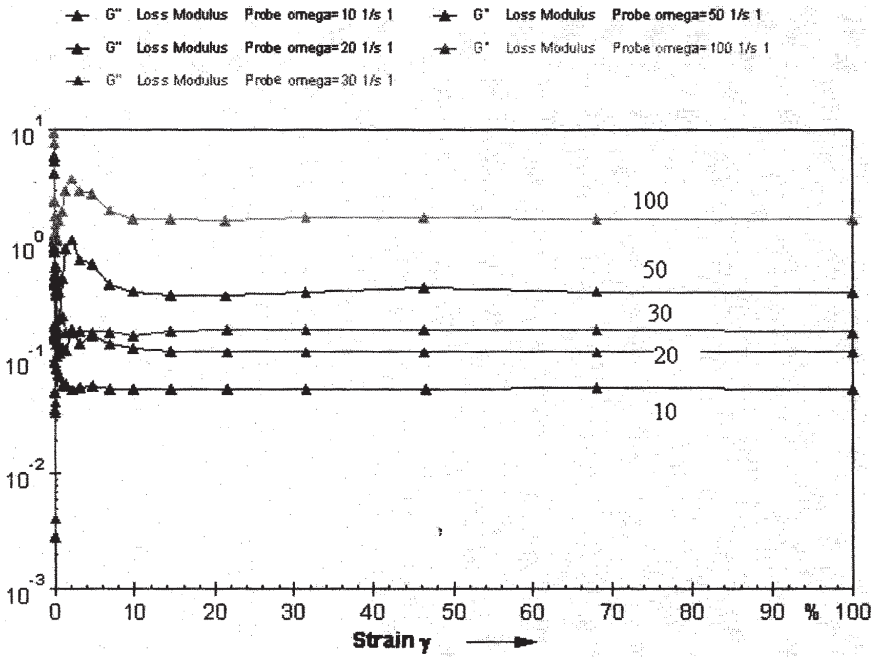

Fig. 6 Amplitude tests at different frequency values (written on curves, in s^{-1}), for the used liquid, at a temperature of 20°C

having thus a slight influence on the dynamic parameters of the liquids.

The curve profile of the complex viscosity as a frequency function, as well as the values of the complex viscosity η* are close to the shear viscosity η as a function of the shear rate $\dot{\gamma}$, a fact which leads to the idea of using the Cox-Merz rule in the case of the studied liquids.

The complex viscosity describes the total resistance in the dynamic shear and the following relation defines it by means of the complex modulus:

$$\eta^* = G^* / \omega \quad (1)$$

where ω is the oscillation frequency, rad/s.

The analogy with the viscosity in the simple shear regime is recommended by the Cox-Merz relation which considers that the viscosity in the stationary regime measured as a shear rate function can be directly compared with the complex viscosity measured as a frequency function:

$$\eta(\dot{\gamma}) = \eta^*(\omega) \quad (2)$$

The advantage of the Cox-Merz relation is given by the fact that it is much easier to work with the frequency than with shear rate. The polymer solutions and melts cannot be measured at high shear rates by using a rotational rheometer because of the elastic effects. That is why instead of using the flow curve in stationary shear regime, one use the dynamic test in order to obtain the complex viscosity. These relations show that one can obtain any oscillating representations if there are data in the stationary regime and vice versa.

The analyzed liquid specimens contain an almost perfect superposition of the η and η* functions, a fact which demonstrates the Cox-Merz rule validity for this case.

Figure 6 presents the variation of the viscous modulus G" as a function of the oscillation amplitude (deformation γ), obtained through the amplitude sweep test by using five values of the frequency: 10, 20, 30, 50 and 100 s^{-1}, respectively. Excepting for the very small deformation zone (under 5%) where the curves show maximum values increased with the increase of the oscillation frequency, the viscous modulus curves become perfectly linear. The G" value increases with increasing oscillation frequency, thus the viscous modulus values are over 25 times higher when the oscillation frequency increases 10 times.

Conclusions

The rheological study of the dielectric fluid used at the machine tools which employ the EDMUS process has been carried out both in the shear flow stationary regime and the oscillatory shear flow regime, at different temperature values. The experimental data have been obtained by using fresh liquid and used liquid after different time values of usage. The results show that the rheological parameters such as the shear viscosity, the viscous modulus and the complex viscosity are influenced by the process parameters and suffer modifications during the manufacturing process. It could be admitted that these modifications do not affect either the flow model of the liquid in the working space or the stability of the technological process.

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