Optimizing Fibre-Reinforced Composites with INForm

Wear resistance of a metal, as well as its strength, can be improved by using reinforcing fibres. Understanding wear and tribological properties of such composites is essential if they are to be used successfully in a range of technological applications.

The traditional approach to gaining such understanding uses statistics, requiring carefully designed experiments for a range of ingredient and processing conditions. More recently, neural networks are being used to complement statistics, since experimental design is not required, historical data can be used, and no assumptions need to be made about the form of the models.

Now, neural computing has been applied to specifically to formulation by Intelligensys. The **INForm** software package integrates neural networks with efficient optimization routines based on Genetic Algorithms. **INForm** lets the user bypass many "what if" questions typically required to find an acceptable formulation, and instead tells the user directly how to achieve certain properties (like good wear resistance with low friction coefficient) with minimum effort.

To use **INForm**, you carry out some initial experiments, and feed these into the neural network directly from your spreadsheet package. Once your models are developed, you can then specify the properties you want, and the optimization process will use the models to tell you what ingredients and process conditions are required to obtain them. In the example given here, the optimization was carried out in seconds, allowing a full assessment of the trade-offs in achieving the different properties. The integration of genetic algorithms with modelling allows the optimum formulation to be predicted more quickly and more reliably than simply assessing response surfaces from straightforward statistics or simple neural network packages.

Alumina-Fibre Reinforced Composites

Zinc-aluminium alloys are being used to replace various iron, aluminium and copper alloys because of their superior mechanical and tribological properties and better castability. Reinforcing these alloys with δ-Al_2O_3 (Saffil) fibres has been shown to enhance strength, modulus of elasticity, creep and wear resistance. Genel *et al*, reporting in *Materials Science and Engineering* A363, 203-210 (2003), have studied the effect of varying the fibre volume fraction, fibre orientation, and applied load, on the friction coefficient and the mass loss rate (a measure of wear).

6 different values were used for the volume fraction, ranging from 0 to 30%. 4 different loads, from 5 to 40 N, were applied. Fibre orientation was either parallel or normal to the surface - although a study using the Intelligensys **FormRules** package showed that orientation was relatively unimportant in determining the friction coefficient and mass loss rate.

The resulting 44 experiments (the results of which are published in the paper by Genel *et al* cited above) were imported directly into **INForm** by typing into the main interface. Copy-and-paste from a spreadsheet package would of course also be possible. 10% of the data records were withheld for validation. Default training parameters from **INForm** were used - **INForm** can select automatically the number of nodes in the hidden layer, and with 3 input variables, the program suggested 3 nodes. This is simpler than the 7 nodes proposed by Genel *et al*, but ANOVA statistics show that our models compare well with theirs.

Model	3 inputs	2 inputs
Nodes in hidden layer	3	4
R^2 for coefficient of friction	99.8	97.4
R^2 for mass loss rate	99.7	98.3

Table 1. ANOVA statistics (in %) for the two "training" options used to develop models

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Initially, we used all 3 inputs in our model. However, because fibre orientation played such a small role, we investigated the alternative case where only applied load and fibre volume fraction were used as inputs. In this case, there are fewer input variables so it is safe to use a larger number of nodes in the hidden layer - **INForm** recommended 4 nodes. The ANOVA statistics for the various models are shown in Table 1 (on the preceding page).

Results

One clear result was that **INForm**, using default parameters, discovered excellent models for both properties - the coefficient of friction and mass loss rate. This is in contrast to the neural network program used by Genel et al, since they had to undertake considerable tuning of their network. So, **INForm** delivered quality results more quickly and with minimal expertise from the user.

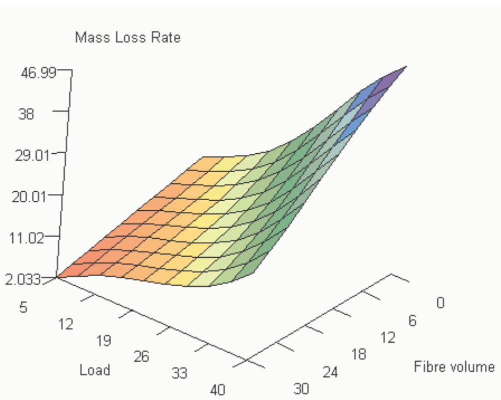

Figure 1. Mass Loss Rate as function of fibre volume and load

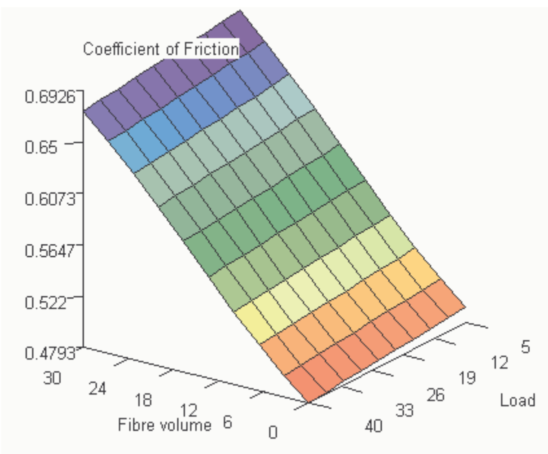

Figure 2. Coefficient of Friction as function of fibre volume and load

Figures 1 and 2 show 3D plots of the models, and have a similar form to those published by Genel *et al*, as expected since both approaches model the data well.

Optimizing Formulations

For optimization, we set the explicit targets that the mass loss rate be as low as possible, with the coefficient of friction being as high as possible, within the experimental data. Of course, this immediately suggested that the load should be reduced - an intuitively obvious conclusion!

With the restriction that the load be set at 40 N (the highest value in the experimental range) the optimum immediately went to the highest fibre volume fractions - again, a result that would be expected by an experienced researcher. This suggests that further experiments, increasing the fibre volume fraction even more, would be valuable.

Conclusions

INForm has been used to model successfully a short-fibre reinforced composite, using the program's default parameters to develop the models. This was considerably quicker than using standard neural network packages. Good models were obtained for both of the measured properties; ANOVA statistics gave R^2 values in excess of 0.98 for each model. This was the case even though the amount of experimental data was limited.

Optimization suggested that, if composites with a low wear rate and low coefficient of friction are desired, then the volume fraction of fibres should be increased beyond the 30% used in the present study. Of course, this could lead to degradation of other properties, unmeasured in this study.

The models also suggested that fibre orientation was not important, and that for determining the coefficient of friction, fibre volume was much more important than the applied load. This result was confirmed with our **FormRules** data-mining program.

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