NEURAL NETWORKS FOR PREDICTING TRIBOLOGICAL EXPERIMENTAL RESULTS

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SUMMARY
In this work, an application of neural network methodology is presented for predicting the wear of a tribological couple (E52100-H13 steel) in a pin-on-disk apparatus. All the experiments were carried out under dry contact conditions. The input parameters for the neural network were load, velocity, relative humidity and sliding distance. The tribological plots of wear-time curves were elaborated and converted in plots of wear-sliding distance. A good match between experimental and neural network curves was observed. Therefore, this innovative modelling methodology has confirmed to be a valuable predictive tool for tribological applications and has shown a significant time and cost saving potential.

Keywords: tribology, pin-on-disk tests, predicting model, neural networks.

1 INTRODUCTION
Modelling in tribology is quite difficult, due to the many parameters involved [1,2]: structural, such as chemical composition and mechanical properties of the triboelements; operational, such as load, sliding velocity, temperature, time, and type of relative motion; interactional, such as wear and lubrication types. Furthermore, the influence of the environment, for example humidity and corrosive gases, cannot be neglected.

Because of the above, tribological models utilize a reduced number of parameters. They are also generally restricted to the investigation of single effects, one by one, such as wear, friction or fretting. Among models, an innovative solution is constituted by the application of a neural network methodology. In the present paper, this approach is used for predicting wear in a pin-on-disk tribometer.

Neural networks have already given promising results in several applications such as medical diagnosis, image analysis, financial investment, process and quality control, failure prediction, and insurance management. More recently, they have been applied successfully in tribology, for example rolling [3], prediction of adhesive wear test [4] and tool wear in machining [5].

It is worth to remind that a neural network must be firstly trained on a group of experimental data, called the training set. Then, the acquired predictive capacity has to be tested on another group of experimental data, called the test set. Once a proper training stage has been performed, which coincides with optimising the weights and biases, the neural network becomes ready for operation. This means that if the neural network is fed with new experimental data, through the input layer, then it will yield suitable data through the output layer. Particularly, the neural network will be expected to predict the output from the input data, in accordance to the experimental (test set) results.

In the present investigation, the training and test sets were related to the experimental data obtained with a pin-on-disk apparatus. The neural network method allowed to predict successfully the wear of the tribological couple.

2 EXPERIMENTAL PROCEDURES
2.1 Tribological testing
The experimental data for feeding the neural network were obtained from a group of 45 tests, utilizing a pin-on-disk apparatus, according to the ASTM G99-95a specification. This apparatus was able to control load and sliding velocity up to 500 N and 3000 rpm, respectively.

All the experiments were carried out under dry contact conditions. The pin consisted of an AISI 52100 (100 Cr 6) ball, having a radius of 5 mm and a hardness of 60 HRC. The disk was made of AISI H13 steel with a hardness of 42 HRC. The centre-line average roughness parameters of the ball and disk surfaces were 0.03 \( \mu \text{m} \) and 0.15 \( \mu \text{m} \), respectively. Temperature during testing was essentially constant at 20 °C with a maximum variation of \( \pm 2 \) °C.

The adopted experimental layout allowed the on-line monitoring, by means of an LVDT transducer, of the distance of a point on the rigid block supporting the ball, from a reference point on the frame structure. The measure of such a distance represented the linear wear parameter.

The experimental layout was carefully set up in order to limit, as much as possible, variations due to external conditions and any other source of noise in the signals, monitored during the tribological testing.

2.2 Neural network
The neural network was based on four input parameters, namely load (N), velocity (m/s), relative humidity (%) and distance (m). Only one output parameter, the linear
wear (mm), was considered. Out of the 45 tribological tests, a subgroup of 35 tests was selected to build the training set, while the remaining 10 experiments were used to arrange the validation test set. The experimental data, taken from the training set, were used to instruct a certain number of neural networks about how to predict the wear master curve in a virtual experiment.

The neural network chosen in this work consisted in a MLP (Multi Layer Perceptron), which usually has a good predictive capacity [3-6]. Several architectures were adopted, such as, for example, a 4-10-5-1 layer scheme. Two hidden layers [4] were adapted to yield a better representation of the tribological phenomena and to obtain a reasonable balance between the convergence rate of the learning algorithm and the accuracy. Finally, the weight and biases tuning was performed through the minimization of the Sum Squared Error (SSE) of the network estimation with respect to the data taken over the whole training set. The Back Propagation and the Levenberg-Marquardt algorithms [4] were used to accomplish the optimisation stage.

An elaboration of the tribological results was carried out. In particular, an elaborated wear-sliding distance master curve was obtained from each original wear-time curve, by evaluating, for each covered distance, the average of several values of the linear wear parameter, taken in the neighbourhood of that distance.

3 RESULTS AND DISCUSSION

3.1 Tribological testing

During the tribological testing, obviously, the higher the displacement of the pin, the more was the loss of mass from the test specimens. However, it was easy to recognise that such a loss was not a linear function of time. In fact, the plastic deformation of asperities resulted into different contact geometries. In other words, the ball became flatter and flatter, while a circular concave path was formed on the disk.

For these reasons, the pin displacement, assumed as a linear wear parameter (mm), must not to be understood as coincident or even directly proportional to the actual mass or volume losses.

The rough (prior to elaboration) plots of the wear-time master curves, as shown in Figures 1 and 2, presented some interesting features.

Appreciable oscillations were observed in all these curves and an explanation follows. It was chosen to measure the linear wear parameter in correspondence to a fixed point of the rotating disk. However, this correspondence was lacking because, even very small variations of the speed changed the point of acquisition. In the example presented in Figure 1, the value of the angular velocity had about a 1% variation.

Furthermore, the upper and lower disk surfaces were not perfectly planar, causing the contact point to rise up and move down, cyclically.

A second interesting observation was the rising up of the pin at the beginning of each tribological test, as evidenced by the negative values of linear wear in Figure 1. This phenomenon could be explained considering that, during the test, several dynamic effects might have led to a smaller total deformation than that taking place during the static loading. Another reason could be due to a build-up of material, such as iron oxide, between ball and disk, during the very first rotations. Finally, incidental pin elevations, such as those shown in Figure 2, might be due to sudden interposition of wear particles between the test specimens.

3.2 Neural network

Figure 3, obtained by elaborating the tribological results represented in Figure 1, illustrates the behaviour of linear wear vs. sliding distance. The elaboration included also the elimination of the negative values of the wear parameter discussed earlier.
Finally, it is worth noticing how the prediction was made difficult by the presence of transitions from mild to severe wear regimes. Figure 4, for example, illustrates a remarkable evolution from mild to severe wear regimes as evidenced in correspondence to 8 N load. Furthermore, during the experiments, it was observed that such a transition was strongly affected by environment humidity.

The predictions of the neural network matched very well the true master curves, obtained experimentally. Four examples of the results, obtained by comparing predicted and experimental master curves, are illustrated in Figures from 5 to 8. The good match points out how the neural network, developed in this work, has achieved the so-called generalization capacity. This means that our network was capable to yield good predictions even under conditions never contemplated during its training stage. A complete analysis of the results of comparing the experimental with the predicted data, over the full test set, estimated a maximum average error in the determination of the linear wear parameter below 8 % with respect to the values obtained experimentally.

4 CONCLUSIONS

The results of this investigation have demonstrated the capability of neural networks to predict wear behaviour of tribosystems. This suggests that neural networks may be very useful tools to have reliable predictions, while reducing the number of experiments. The progressive implementation of such innovative methodology can lead to significant time and cost savings.
Figure 8: comparison of experimental (thin line) and predicted (thick line) master curve (load = 6 N, sliding velocity = 0.3 m/s, relative humidity= 48%)

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6 REFERENCES