The Use of Neural Networks to Identify Anodizing Process Defects

By A.W. Brace

In this second of two papers on potential uses of computers in surface finishing, the advantages of specialized programs, such as neural networks programs and others employing "fuzzy" logic are described. These advantages are illustrated by example and are intended to acquaint finishers with their potential.

Although rarely discussed, it is a fact that all metal finishing shops produce some work that is rejected. This is of importance because it incurs extra costs (*i.e*., the costs of reprocessing, plus the profit that could have been made on the components which would have been produced if the work had been correctly processed originally), and sometimes loss of goodwill on the part of the customer. Experience of investigating rejects resulting from anodizing processes indicates that their origins result mainly from the following:

1. Accidental handling damage.
2. Incorrect finish resulting from failure to read paperwork correctly.
3. Defects originating in the material or prior manufacturing processes.
4. Defects arising from inconsistencies in processing occurring occasionally.

Defects attributable to items 1 and 2 above are easily recognized and the remedies are usually obvious. Identifying material defects often requires specialized metallurgical knowledge that the average anodizer lacks. The defects belonging to category 4 are essentially process defects.

Previous Publications on Defects

Several papers have been published regarding individual process defects. These can best be summarized in relation to the particular process to which they refer. Most of the early papers (*i.e*., prior to 1960), were mainly reports of *ad hoc* problems solved by anodizers. As the range of processes increased and quality standards were raised, the need for systematic research was recognized.

In the 1960s, bright anodized aluminum trim began to be used on a large scale. This resulted in papers from a number of authors reporting on the factors that caused lack of brightness when using the proprietary chemical brightening baths, with particular reference to the role of nitric acid and copper, as well as factors affecting the incidence of transfer etch in automatic plants.

The influence of metallurgical factors on brightness was also widely investigated. Loss of brightness during anodizing was also found to be affected by anodizing conditions, the presence of low levels of heavy metal impurities in the anodizing electrolytes, and even the ramp rate used in attaining the operating current density. Factors affecting the incidence of pitting in dye baths were investigated, as well as the problems of measuring and maintaining the required color.

Growth of the use of anodized aluminum on buildings gave rise to concern with quality and long-term performance. This stimulated a large number of papers evaluating methods for measuring anodic film properties, such as thickness, sealing quality, abrasion resistance, corrosion resistance, hardness, reflectivity, wear resistance, coating density etc. Useful summaries of the findings have been made in three well-known reference books.[1-3]

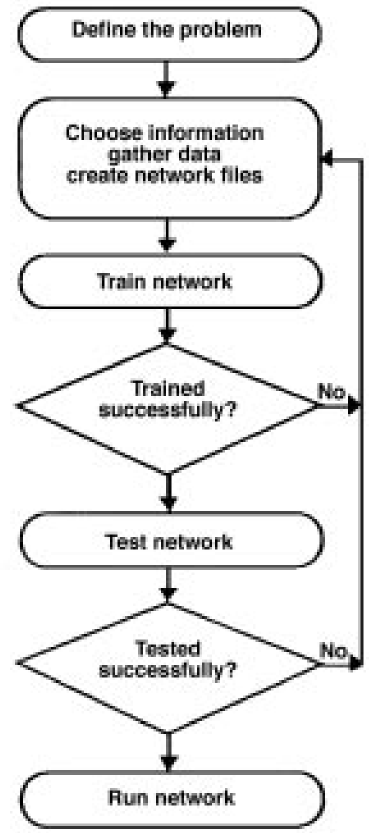

Fig. 1—Flow/logic diagram for development and testing of a neural networks program for identifying anodic coating process defects.

Other papers with a broader approach to defects have appeared, but they are mainly of the "troubleshooting" kind[4,5] and lack a systematic, rigorous approach. A paper by Short and Bryant[6] has been for some years the only paper providing information on a useful number of defects and their origin, but many of them are of material defects. Personal experience indicated that in many plants the steps taken to overcome the incidence of defects on a particular batch of work depended mainly on prior experience. If the defect cannot be recognized, then purely *ad hoc* steps are taken to deal with the problem.

In the course of providing advice to anodizers on problems, it became evident that production personnel often lack training in the steps needed in a systematic approach to identifying unknown defects. The inevitable pressure on production personnel to produce a quick *ad hoc* answer to meet customers' delivery schedules reinforces the need for rapid corrective measures. In an attempt to assist by offering a readily available practical guide to defect identification, a paper was published[7] containing an algorithm which, after guiding the user in identifying the process stage at which the defect occurred, directed the user to answer various questions that should lead to identification of the specific defect. In all, about 60 defects were included, some of them being material-related.

Subsequently, the total number of defects identified increased to well over 100 (some were material or manufacturing defects) and were published as a book.[2] Advice was also offered on the steps needed to avoid or correct the defect(s). Later experience showed, however, that the algorithm was not always adequate in enabling users to identify an unknown defect, while the book lacked ease of cross-referencing to defects having some degree of similarity. This led to an assessment of the possibility of using computer-based information technology to handle the problem.

The objectives defined in deciding on this approach were as follows:

1. To locate or develop a suitable program, by means of which users would be automatically guided into a systematic approach to analysis of defects. It would be expected to result in rapid identification of defects with a high probability of being correct.
2. Such a program would be able to guide the user in finding the process stage at which a defect had developed (*i.e*., cleaning, etching, anodizing etc.).
3. The program should be capable of being developed into an expert system that would probably provide a database and as a facility for a graphics display of the defect.

Logic-based Expert System "Shells"

At the time of commencing this work, a number of expert systems had been developed and were being applied to various problems. Such expert systems are based on a computer program known as an expert system "shell" (*i.e*., a programming framework that can be used to incorporate the required expertise. Examination of several expert system "shells" presented a philosophical problem, as has been discussed elsewhere.[8,9] These expert systems depend upon answers to questions embedded in the system to a which a *Yes/No* answer was required. Depending on the answers, the user would be presented with a reply that relied on the logical operators in the program:

If (yes/no to certain facts) ......, then:
.... (certain conclusions as to their origin).

This approach presents problems, however, since it implies that the user knew the conditions prevailing when the problem occurred, to be able to answer *Yes* or *No* with 100 percent certainty. Personal experience of investigating processing defects has been that, in most cases, when asked what the conditions were at the time the problem occurred, personnel would give answers which, in fact, merely confirmed the standard process schedule, often with limited evidence to support the statement. Others were more constructive, in that they would advise that they did not know at the time if conditions were as they should be. Such uncertainties indicated that existing expert system "shells" might not be the most fruitful approach to the problem, although some attempted to build-in probability factors in arriving at the expert system rules.

Perceived Advantages of Using Neural Networks For Defect Identification

Perusal of the computer technical press at this time resulted in evaluation of several neural networks programs and acquisition of one of them.[9] This type of program falls within the bounds of computer-based knowledge ("artificial intelligence"). The program is an example of the use of "fuzzy" logic in conditions of uncertainty, in that numerical values cannot be allocated to describe the defects, so it lacks precision. A further problem is encountered when subsequent processing has changed the appearance from that seen when the defect was produced. This can occur, for example, when a defect arising in a mechanical pretreatment or cleaning is subsequently etched.

Adapting the Neural Networks Program For Defect Identification

The characteristics of neural networks have been discussed elsewhere.[8,9] They excel at recognizing patterns, whether of alphanumerics or graphics, and take into account a lack of precision in the data entered. Process defects can be described alphanumerically and are converted by the program to digital values. Essentially, the program compares the digital values of each line of the data entered by the expert with the data entered by the user to describe the defect.

The program then provides a numerical value between 0.10 and 0.90 as the probability of the identification made by the user being correct. The program selected can remain memory resident, thereby providing rapid access to and from other programs, such as a database or graphics display, which might be used in providing a full expert system.

The Logic Diagram

Use of the neural networks program to identify anodic coating process defects involves a number of steps defined in the diagram of Fig. 1. The first critical step is to break down the identification of the defect into a number of files, each of which contains features associated with defects that can occur at each process stage. A limitation of the program is that the description of the defect must be limited to one line as displayed on the screen.

Preparing the Neural Networks Files

The basic file structure is relatively simple. Essentially, the program is based on pattern recognition. When the user operates the program, it compares the pattern of the inputs of the person who prepared the data for the files with the data entered by the user. To do this, the compiler of the data must confine the definition of a feature of a defect to the number of characters that can be displayed on one line and therefore cannot exceed 80. A similar restriction applies when entering the description of the defect. As will be seen from Figs. 2 and 3, this involves providing a one-line description of each feature associated with any group of defects. In practical terms, this usually means that the data are prepared on a word processor and rearranged to suit the requirement of the program, then exported as ASCII text into the NeuroShell™ program. This is followed by preparing a series of examples referred to as "cases," in which suitable "identifying characteristics" are entered in the top half of the screen and the "classifying characteristics" in the lower half. When this is complete, the computer is instructed to "learn" these cases, in the course of which a back-propagation neural network is constructed. At this point, the program is tested by entering cases (*i.e.*, features of defects), not using the data employed in compiling the file, but using various combinations that might be entered by users with lesser expertise. If the results are not satisfactory, the data and cases may have to be modified.

The essential first step is to ask the user to identify at what process stage the defect may have occurred. This primary classification of process defects has been suggested in a previous paper.[7] This can involve partial stripping of the anodic coating in a chromic-phosphoric acid solution to confirm whether the defect was below or within or on the surface of the anodized component. The first step in the expert system is to answer the following question:

Does the defect appear to be:
(i) Beneath the anodic coating?
(ii) Within the anodic coating?
(iii) Associated with sealing or surface deposits?
(iv) Associated with the material?

Using this approach, the various files that have been compiled fall into the following groups of filenames intended to be self-evident descriptions of the main groups of defects:

Beneath the anodic coating	Within the anodic coating	Sealing or surface	Material-related
MECHDFTS	ANODFTS	SEALDFTS	Consult expert
BRITEDFT	COLORDFT		
CLEANDFT ETCHDFTS			

Using the Neural Networks Files For Defect Identification

Primary Identification

Experienced anodizers are likely to answer questions (i) to (iv) listed above and to recognize which of the above files is likely to assist them in the identification of a specific defect. On the other hand, less experienced anodizers may need some assistance in making this primary identification. To this end, a file, IDENTDFT, was developed to assist the user in identifying the process stage at which the defect originated, or whether it is a material problem. In compiling the IDENTDFT file, a total of 57 cases was entered. These utilized combinations of 17 identifying characteristics seen above the dotted line displayed on the screen and 12 classifying characteristics displayed below the dotted line, as shown in Fig. 2. Having compiled these various files of different groups of defects, the program can now be used to identify a defect. The IDENTDFT file is loaded and the user, for example, highlights the following two lines:

The defect is within the anodic coating
The appearance of the work is unsatisfactory
———————————————————-

On pressing the appropriate function key, the following line is highlighted in the lower half of the screen:

———————————————————-
This is an anodic coating defect - see the ANODFTS file - 0.91

It will be noted that the numerical value appears at the end of the line, indicating the probability of the answer being correct. An important feature of the program is that in evaluating the probability of the identification's being correct, the computations carried out are based on the assumption that 100-percent certainty of the answer's being right or wrong is not possible. Usually, the maximum probability shown is 0.90 ±0.01. For those defects displayed that are unlikely to be the correct identification, a value of less than 0.50 will be displayed.

A further example of a possible entry for identifying a defect is the following:

The defect is beneath the anodic coating
The finished work has a patchy, non-uniform appearance
After etching the components have an unsatisfactory appearance
———————————————————

On pressing the appropriate computer keyboard function key, the following is displayed in the lower half of the screen:

———————————————————-
Cleaning defects are classified in the CLEANDFT file - 0.91
Defects arising in etching are classified in the ETCHDFTS file - 0.90

Using the Files of Neural Networks Program

Having been advised, for example. that there is probably an anodic coating defect, the user then loads the ANODFTS file as shown in Fig. 3.

If the user of the IDENTDFT file entered the line containing "unsatisfactory appearance" in the IDENTDFT display, it could be because of a dull appearance. This can be the result of the following causes:

———————————————————
The defect is beneath the anodic coating
The defect is within the anodic coating
The defect is associated with sealing or coating surface
The defect appears to be of material origin
The component is an extrusion and has an uneven appearance
There are signs of pitting, staining or white spots
The component is made from a casting
The component has been made from sheet and has an unsatisfactory appearance
The component has been fabricated by brazing, forming or welding
The surface has been mechanically treated and is of unsatisfactory appearance
The work has been chemically polished and is of unsatisfactory appearance
After etching, the components have an unsatisfactory appearance
After anodizing the coating is unsatisfactory, the thickness obtained is incorrect
Properties of the coating when tested are incorrect
The work has been dyed or electrolytically colored
After dyeing or coloring, the appearance is unsatisfactory
The coating has failed one or more sealing tests
After sealing there is a surface discoloration or surface deposit
———————————————————
For anodic coating defects - see the ANODFTS file -
For defects in chemical brightening - see BRITEDFT file -
For defects arising in castings - consult an appropriate expert -
These are cleaning defects - see the CLEANDFT file -
For corrosion defects - consult specialist -
Defects arising in etching - see the ETCHDFTS file -
To identify defects in extrusions - consult supplier -
For defects arising in manufacture - discuss with customer -
For defects arising from mechanical pretreatment - see MECHDFTS file -
For defects which appear to originate in the sheet material - see supplier -
To identify defects arising in sealing or on the surface - see SEALDFTS file -
———————————————————

Fig. 2—Screen display of the identifying and classifying characteristics entered in the IDENTDFT file.

The work has been sulfuric acid anodized
The work has been chromic acid anodized
The work has been hard anodized
Uneven protrusions in the form of blisters are seen on the surface
There are areas with a rough, uneven appearance, which may be unanodized
There are rough areas around one or more holes in the metal
The anodic coating has fine pits present and there is chloride in the electrolyte
The film produced in chromic acid anodizing is clear
When viewed at a glancing angle to light, fine lines (cracks) appear
The coating appears duller than usual after anodizing
The dulling increases with film thickness and current density
The dulling is associated with the presence of heavy metals in the electrolyte
There are white areas on the surface of the work absent before anodizing
The sulfuric acid electrolyte contains more than 20 g/L aluminum
There is fine pitting present but no chloride in the electrolyte
There are irregular pits in the anodic film after anodizing
There is patchiness having a pattern associated with the draining direction
The coating has a powdery surface which can be removed by rubbing
When viewed at a glancing angle to incident light a "rainbow" effect is seen
Some or all of the parts do not meet the expected or specified thickness
The coating fails the hardness or abrasion test

This defect is classified as "blistering"
This defect is due to "burning" of the anodic coating
This defect is the result of chloride pitting
The cause of a "clear chromic film," is the presence of sulfate
This defect is a crazed anodic film
For the causes of "dulling in anodizing," check for high current density
This is "dulling from contamination"
Excessive aluminum content—check reference books
This is a result of "galvanic pitting during rinsing"
These cavities result from inter-metallic dissolution
This feature is known as "iridescence"
This is characteristic of a "powdery anodic coating"
This is characteristic of a "soft anodic coating"
Wrong film thickness—check reference books

Fig. 3—Screen display of defining and classifying characteristics of anodic coating defects contained in the ANODFTS file.

1. Dulling of the coating from use of high current density.
2. Metallurgical factors, such as precipitation of intermetallics.
3. Contamination of the electrolyte with heavy metals.

We can now examine the way the program identifies anodizing defects using the ANODFTS file. If the user highlights the following identifying characteristics, the program classifies the defect as follows:

The work has been sulfuric-acid-anodized
The coating becomes duller than normal after anodizing
The dulling increases with thickness and current density

This is classified as "Dull appearance" - 0.88.

When using the ANODFTS file, a user may enter incomplete information relating to "dulling," such as the following:

The work has been sulfuric-acid-anodized
The coating becomes duller than normal after anodizing

In this case, a message appears at the top of the screen:

No classification exceeded the threshold

The following two lines appear, however, in the lower half of the screen:

This defect is "Dull appearance" - 0.47
This defect is "Dulling - contamination" - 0.38

Because the probability values are far higher than for any of the other defects, it provides a clue to their possible identification. In general, plants do not check the heavy metals content of the electrolyte. If, as a result of the above display, their content is checked and the following lines entered:

The work has been sulfuric-acid-anodized
The coating becomes duller than normal after anodizing
The electrolyte contains <50 ppm heavy metals

In the lower half of the screen the following line is also displayed:

This is classified as "Dulling - contamination" - 0.89

The file also provides classifications if two defects are present. Suppose the user enters the following identifying characteristics:

The work has been sulfuric-acid-anodized
There are white patches on the work not previously seem
There is patchiness associated with the draining direction
The coating has a powdery surface that can be removed by rubbing

On pressing the classifying function key, the following is displayed:

This is "Patchiness - poor rinsing" - 0.60
This is classified as "Powdery coating" - 0.55

The above shows that, based on the information entered, the two defects shown have a reasonable probability of being correctly identified.

One basic advantage of neural networks is that they not only can identify two defects if they occur together, but they can provide the user with a reasonable probability of the identity of a defect even when two defects are present, and when incomplete information has been entered. This can be illustrated with an example from the ETCHDFTS file. If a user has an etching defect and looks at the screen display and sees the line:

There are stain marks in the direction of draining the work

On pressing the function key the following is highlighted in the lower half of the display:

These are the characteristics of "etch staining" - 0.62

If, however, the user also observes and enters the following line, the probability of the defect classification's being correct is increased from 0.62 to 0.90.

These stain marks are more evident on heavy sections

Of course, there can be two defects occurring simultaneously, such as poor appearance as a result of incomplete stripping of the anodic coating on defective work prior to anodizing. The user might then select the following lines for display:

There are stain marks in the direction of draining of the work

These stain marks are more evident on heavy sections
There is a differential etch pattern with localized rough patches

These are the characteristics of "etch staining" - 0.83
This results from "incomplete stripping of the anodic coating"-0.43

This now shows that although the information is incomplete, the program detects the possibility that there is a second defect present, "incomplete stripping," because the 0.43 value for the probability is so near threshold value of 0.50 that the user should recheck the observations made. Supposing this results in the following line being also additionally entered:

The work has been anodized and stripped in a caustic soda solution

On pressing the "classify" function key the following is displayed:

These are the characteristics of "etch staining" - 0.71
This is incomplete stripping of the anodic coating - 0.82

It can be seen that not only can the neural networks program correctly identify a single defect but can also assess the probability of a second defect being present, provided the user has made the appropriate observations. It also has the merit that even when there is the probability of the identification's being correct, it can provide an indication of the need for the user to recheck the observations made if the probability value is 0.33 to 0.49.

An additional facility can be provided in conjunction with the various neural network files which is a hypertext link with a database containing more information. This could be a set of bibliographic references or a record of previous instances when the defect occurred and/or the remedial action needed.

Summary

The information above constitutes an innovation in the approach to developing an expert system for the identification of anodizing process defects. Obviously, it can be modified and applied to a range of metal finishing problems. Neural networks programs have already been widely used in other branches of manufacturing industry and have a number of advantages over logic-based expert systems. Of course, they are not a panacea for processing problems, but rather represent an additional but valuable tool where the data are uncertain or the ability to recognize patterns may be of assistance in solving process problems. When this study was initiated, the program used was MS-DOS™- based and could be integrated into DOS-based programs to display graphics or link with a database. Now a Windows™ version[11] of the program is available that has improved graphics capability; and there is a wider choice of database and hypertext programs with which it can be integrated.

Editor's note: *Manuscript received, September 1998.*

Acknowledgments

Special thanks are due Ted Short, formerly of Alcan's Banbury Laboratories, who was most helpful in providing examples of defects and background information. Also, over the years, Peter Sheasby has ungrudgingly shared his expertise when approached for comment on the origins of defects. This work was in part fulfillment of requirements for a PhD at Aston University, Birmingham, UK. Thanks are also due my joint supervisors, Dr. J.K. Dennis and L. Crane of the Department of Production Engineering.

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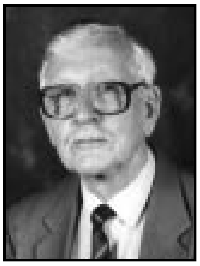

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