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Numerical control of laser processing and simulation of microstructures and temperature profiles - a fuzzy approach

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ABSTRACT

The use of high-power density laser beam for surface modification of many important alloys often leads to appreciable changes in the composition and tribological properties. These changes are dependent on process variables such as beam size, energy, scan rate, laser mode and the Chemistry and metallurgy of steel. Approximate solutions to heat flow equations are combined with kinetic models to predict the microstructures and temperature distributions. A transient fuzzy logic based heat flow model is developed to predict temperature zones instead of discrete temperature calculations. A set of separate membership functions are formulated for determining temperature zones by means of continuous iteration process the same method is adopted to evaluate microstructures for a specific temperature zone by incorporating the kinetic and thermal datas available. Alloy steel of CK45 grade and stainless steel of 316 grade are used for this investigations and the results obtained are compared with the temperature profiles obtained from conventional methods and hence their microstructures. An attempt is also made to compute the dendrite cell width distribution during laser melt solidification of 316 LN steel by means of the above mentioned method.

INTRODUCTION

The success of laser processing of steels depends on the setting of the optimized process parameters and their continuous monitoring during the processing period. This often leads to larger time consumption and leads to poor tribological properties. Also, due to tolerances resulting, a simulation of various working parameter such as power, temperature, scan speed, beam radius and power distribution becomes a necessity for ensuring high quality standards.

Previous attempts at solving this problems based on conventional (analog) and finite elemental methods[1,2], have not always lead to satisfactory results in the setting of optimized process parameters. Even today the use of expert systems for process parameters setting in on-line use is still at beginning because such systems are unstable for real time applications[3].

With fuzzy logic the possibility of modelling in real time has gained importance due to the availability of faster computing capabilities. In the following, the prediction of a rule-based model for process parameters optimization for laser processing of steels are discussed. The laser treatment results obtained from processing of 9 Cr-1 Mo alloy steel is used as the data for the on-line modelling[3]. Relevant programmes are written in "C" language as support to the control mechanisms.

FUZZY APPROACH

For establishing conventional control process algorithms the availability of a mathematical process model is essential. Table-1 gives an overall view of physical parameters which influence processing and also reveals the mutual interactions between them. The next step in devicing a process control algorithm therefore involves specifying the mathematical relations of the model[4]. The number of complexity of these equations increases with the increasing number of process variables.

Table - 1

Laser Power :	Current range Gas flow Pressure	Environment :	Temperature Humidity Pressure Process Condition
Scan speed :	Synchronism Tolerance		
Shielding gas :	Composition Pressure Homogeneity Quantity	Beam :	Mode Radius Focussing Condition
HAZ (Heat affected zone) :	Rate of cooling Thermal conductivity Reflectivity (surface)		

A material processor obtains its informations for processing parameters mainly from visual and acoustic perceptions. To help in understanding process control developed on the basis of fuzzy logic the following principles are explained. As already stated the statements concerning the controller behaviour appear in linguistic forms. These statements do not refer however to precisely expressed physical quantities of the form "temperature = 800°C", but to imprecise statements like "temperature is low". At first step, therefore it is necessary to transform the physical quantities into fuzzy variables. This is done by so called membership functions. One can imagine such as membership function as an allocation to certain grades. Fig. 1. shows membership function for allocating the temperatures distribution in the material to four grades "too low", "rather low", "rather high" and "too high". The process of obtaining fuzzy variables from physical quantities is known as "fuzzification".

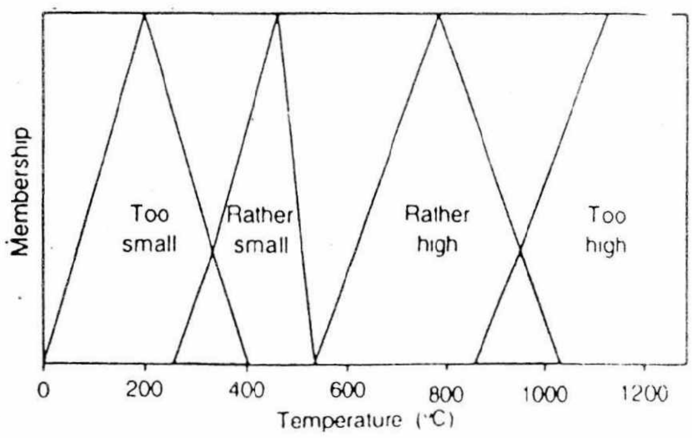

Fig. 1 : Example of a Membership Function

The further operation of fuzzy logic then refine the degree of membership in such grades. For this AND on OR operators - as shown from binary logic are available. Their involvement supplies the degree of membership of the target variables within a grade. Mathematically the AND involvement corresponds to a determination of the minimum. The OR involvement to a determinant of maximum (Fig. 2).

To be able to control a physical process with a variable value obtained from a fuzzy logic link, this fuzzy variable must be transferred again into a physical quantity. For this transformation, so-called "defuzzification", several methods exist[5]. The method of heights will be discussed here. First all the areas of membership functions of the target variables are reduced to a previously calculated grades of membership. The physical variable used is then determined by forming a centroid (Fig. 2).

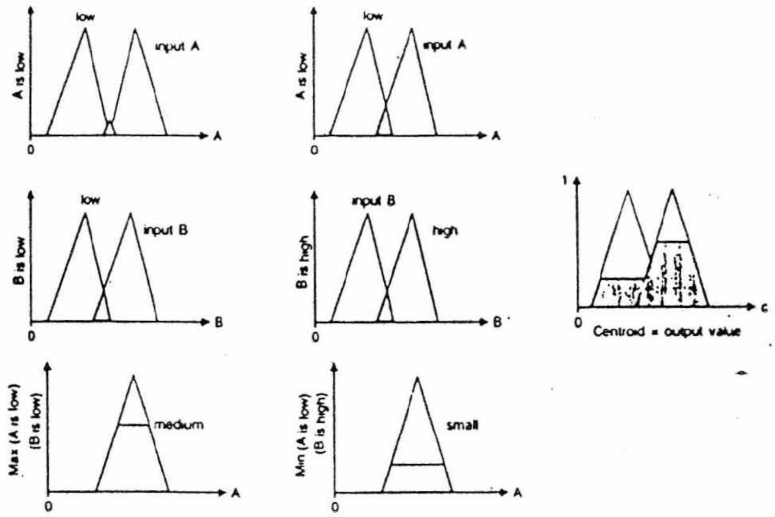

Fig. 2. Method of Heights

PROCESS PARAMETERS

To design the rule base it is essential to convert the physical parameters into linguistic variables. For this precise knowledge of physical process and an estimate of the work involved in the measuring methods are necessary.

During laser treatment, processing of 9Cr - 1Mo material with 2 to 5 mm thickness was selected. Fundamental considerations in the design of the rule base are the choice of manipulated variables and measure of quantities and estimating the requirements which are imposed with regard to the real time capability of the data processing system.

1. Laser power (watts)
2. Scan speed (m/min)
3. Beam radius (mm)
4. Material properties (λ,a,A)

On-line variation of beam radius is usually not possible in these circumstances, however, it is set before the process is initiated. It was taken that the scan speed and laser power are taken as manipulated variables. In this regard the recording of Power (current) and Scan speed (voltage) can be achieved in the laser generator.

An examination of the signals obtained from calculations made at various power and scan speeds showed not scanning current and voltage signals at a frequency of 260 Hz was sufficient.

RULES FOR PROCESS DIAGNOSIS

Extensive test processing was performed for developing the algorithms for the process diagnosis. It was clear that simply taking an average of the measured value is not sufficient. Since the measured quantities, power, scan speed are linked with occurrence of microstructural development and hardness the type of microstructure and hardness number can be calculated. To reduce the huge quantity of data involved a comparison is made with the previous data base of 9Cr - 1Mo steels[6,7,8].

Fig. 3 gives statistical values relating the membership of the temperature (power) and scan speed (voltage) are used as the input variables for these modules. By calculating the grade membership the desired data reduction is also achieved.

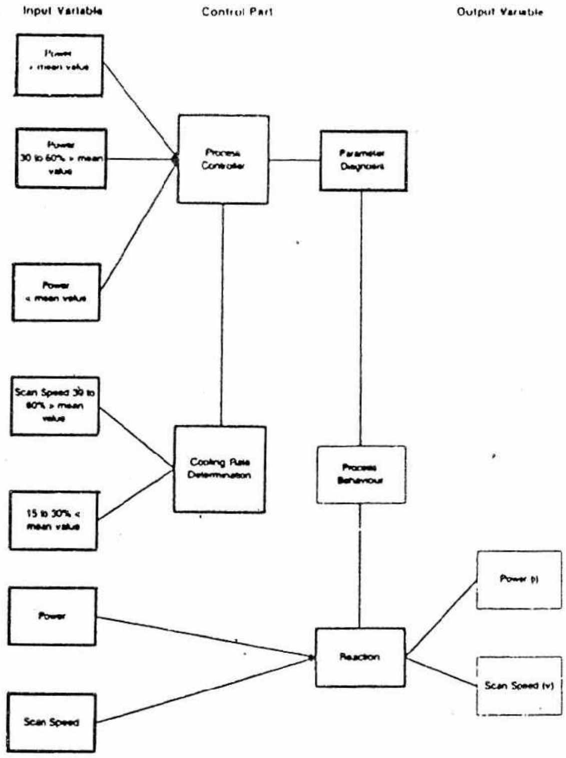

Fig. 3 : Block Diagram of Fuzzy Controller

The rules for microstructure phase formations and attainable hardness values relating to percentage of metallurgical phases and elemental compositions, yield fuzzy variables. The block reaction is discussed in detail at Fig. 4. The input variables are calculated from the signal curve to laser power specification (Input Current) and stepper motor voltage readings. New settings of the materials are implemented, subsequently using two variables "Power" and "Scan Speed".

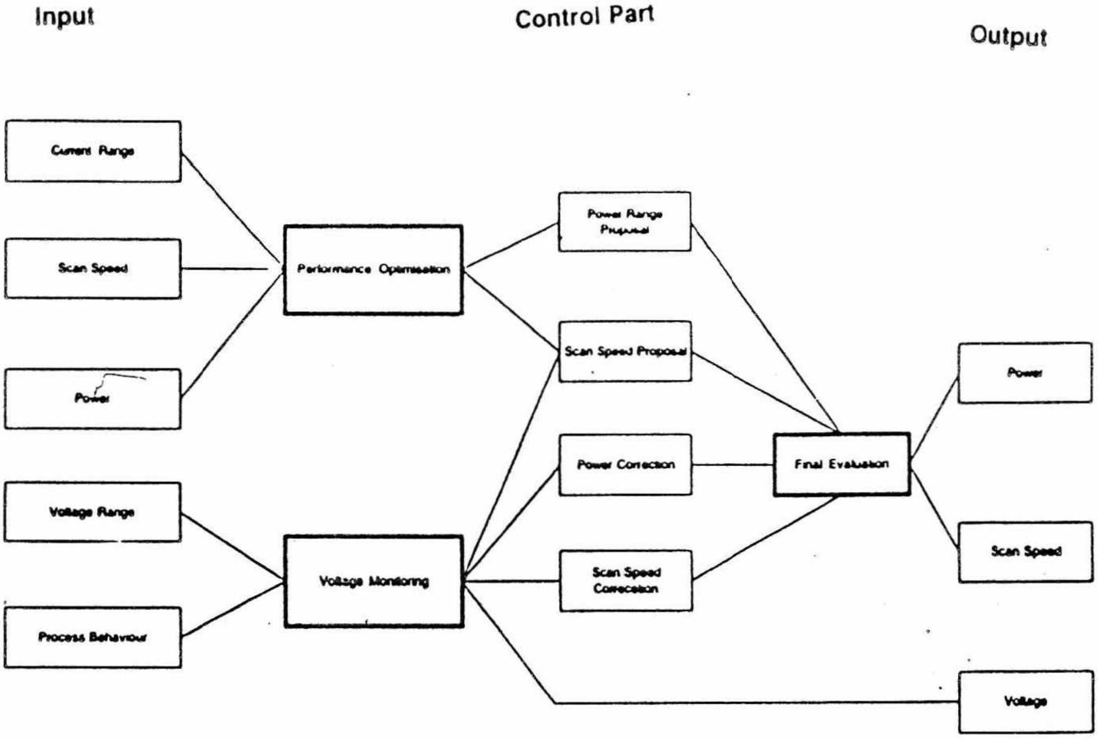

Fig. 4 : Block Diagram of Module Reaction

In order to stimulate the operating point, the diagnosis module for performance optimization was designed[7]. It calculates whether the processing is carried out in the required microstructural range. Process diagnosis is based on the results obtained from the module "Process behaviour" and "Process optimization". In addition to the values for stability (module "Process behaviour") and values of current range (Process optimization), the required power should be specified (Microstructure).

The careful examinations of the process diagnosis modules created reveals that they have great similarity with parts of an expert system. Since fuzzy systems contains expert knowledge which is relevant to artificial intelligence with a rule base for process parameter, learning ability is dispersed and maintains control over the process.

CONCLUSION

The design of fuzzy-based temperature (power) and scan speed (cooling rate) control expert knowledge has enabled a "tool" to be designed for on-line process. This would lead to

1. reduced processing error

2. reduced number of trials
3. improved real time control.

The system concept developed is suitable for supervising a material processing process and for processing a data obtained in real time. The process computer contains modules of real time process diagnosis. The recording of these process is also easily possible with a computer. Since the number of rules to be evaluated greatly influences the calculation time, however, solutions with lesser number of rules are to be designed for real-time applications. A possible idea is to store fuzzy rules in database and this would help in pre-selection of membership functions for a concerned process.

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