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정성적지식과 퍼지다기준 의사결정을 활용한 최적연삭숫돌선택법

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Selection of Optimum Grinding Wheel Based on the Qualitative Knowledge and Fuzzy Multi-decision Making

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ABSTRACT

연삭숫돌 선택은 공작물제거량, 숫돌의 소모량, 표면정도 및 공작물의 물리적·화학적 특성을 고려하여 설정하는 것을 기본으로 한다. 연삭가공은 구성인자의 상호관계가 복잡하여 이중에서 어느한 요소만을 고려하여 설정하기 어렵고 정량적 기준 또한 정해져있지 않아 현실적으로는 숙련자의 정성적이고 경험적 지식에 따른 주관적 척도에 의존하는 것이 대부분이다. 또한, 연삭숫돌은 작업조건중에서 대량생산을 제외하고는 되도록이면 현장에 구비되어 있는 작업가능한 연삿숫돌 중에서 선택하는 것이 바람직하다.

따라서, 본시스템에서는 이와같은 점을 고려하여 최적 연삿숫돌선택을 퍼지이론에 기초한 현장 숙련자의 지식을 활용하므로써 연삭숫돌선택의 효율성을 도모하는 동시에 현장에 연삭숫돌이 구비되지 않은 경우도 고려하여 연삭숫돌설정에 우선순위를 제시하므로써 작업자에 연삭숫돌선택의 유연성을 부여하였다.

또한, 실용성있는 전문가시스템의 구축을 위해 정성적이고 경험적인 지식의 활용을 위한 지식표현으로 설문조사에서 얻은 데이타를 x^2-分布에 따른 추정신뢰구간을 구해, 이를 토대로한 비대칭 삼각퍼지함수의 결정법을 제시하고, 이를 이용해서 구축한 시스템의 실행결과의 타당성을 비교하고자 한다.

Key Words : Grinding Wheel, Qualitative Knowledge, Fuzzy Logic, Order of Priority, Analytic Hierarchy Process, Fuzzy Multi-decision Making

1. INTRODUCTION

Selection of optimum grinding wheel is generally performed by taking into account the grinding efficiency and accuracy. But, it is mainly dependent upon the knowledge of skilled operators because the causal relationship connected with grinding operations is not

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only complicated by inter-relationship of parameter but also is not generally prescribed for the quantitative analysis. It is desired that grinding wheel in a workshop would rather be used than others, if possible. That is, if the best grinding wheel recommended by the developed system is not equipped in a workshop, it is practical to use the next best grinding wheel for the purpose of improving the grinding efficiency, specially, since there is sometimes effective method for a small lot size.

Therefore, in this study, design of grinding knowledge-base is applied to non-symmetrical triangular fuzzy membership function for the purpose of ulitizing the knowhow and empirical knowledge of a skilful expert. Selection of grinding wheel adopted the fuzzy multi-decision making.[1,2] Its merits can be given to the flexibilty by means of suggesting an order of priority at the selection of grinding wheel. As the result, this system can not only reflect the situation of a working shop but also utilize the empirical knowledge obtained from a skilful expert. Moreover, knowledege representation accumulated in knowledge-base designed the non-symmetrical triangular fuzzy function considered the reliability area analyzed by χ^2-distribution curve.[3]

2. DETERMINATION OF FUZZY MEMBERSHIP FUNCTION BASED ON THE QUALITATIVE KNOWLEDGE

Selection of grinding wheel for the constraints such as the surface roughness, allowance and accuracy of workpiece is accomplished by satisfying the surface roughness as well as maximization of the material removal rates. In the case of grinding wheel, evern if the best grinding wheel according to the input constraint is suggeseted, if it is not equipped in a workshop or lot size is very small, we would rather operate the next best grinding wheel than to purchased new grinding wheel. It can be accomplished by giving the order of priority about selection of grinding wheel within the selectable area. That is to say, it means that application of priority rule can satisfy a grinding efficiency according to utilizing the next best grinding wheel. This method would improve the grinding efficiency rather than operate the new grinding wheel. Furthermore, since the selection of grinding wheel is actually dependent upon a knowhow and an empirical knowledge of skilful expert, therefore, it is necessary to design so that the grinding database can reflect on these problems described above on the selection of grinding wheel.

For the purpose of allowing the flexibilty, knowledege representation adopted the triangular fuzzy membership function based on the fuzzy logic.[4] Fuzzy membership function accumulated in the grinding database is represented gy the non-symmetrical triangular form which considers the degree of freedom and properties of data.

2.1 Questionnaire Method and Analysis of Data

Questionnaire paper in order to construct the database for the selection of grinding wheel are performed on the skilful experts worked 3 years or more in a grinding workshop. For instance, format of questionnaire papers are as follows:

(Example of the Selection of Grain Size)

Would you check the items given in below format, if any you operate the cylindrical plunge grinding for SUJ2(workpiece) and 5㎛ R_{max}(surface roughness). The disclimination of surface roughness is given as follows:

Roughness grinding(R_{max} 6㎛ ir more), Normal grinding(R_{max} 6-3㎛), Fine grinding (R_{max} 3-1.5㎛), Precision grinding(R_{max} 1.5 and below)

(1)#:
[0---0.1---0.2---0.3---0.4---0.5---0.6---0.7---0.8---0.9---1]
(1)#:
[0---0.1---0.2---0.3---0.4---0.5---0.6---0.7---0.8---0.9---1]
(1)#:
[0---0.1---0.2---0.3---0.4---0.5---0.6---0.7---0.8---0.9---1]
(1)#:
[0---0.1---0.2---0.3---0.4---0.5---0.6---0.7---0.8---0.9---1]

In the similar method, we carried out making a questionnaire five components of grinding wheel in terms of grain, grain size, grade, structure, and bond. The discriminated width of data are given to the number 0.01 listed above in the format of questionnaire papers.

On the other hand, acquisition of data on each of the wheel components are obtained from skilful experts of about 50 persons. Among the questionnaire results, we selected the 35 data for grain and grain size, and other whell components of grade and structure selected the 25, respectively. And then on the base of questionnaire results, we analyzed the characteristics of the binominal distribution, and so calculated the mean μ, standard deviation σ, and variance ν of data for each parameter to the purpose of adopting the knowledge representation.

As the result of analysis, we know that the binominal distributions are characterized by x^2-distribution curve, and they are utilized on the knowledge representation of grinding database in order to establish the grinding wheel.

That is, the upper and lower limit of reliability area shown in Fig. 1, (represented by x_α^2 and x_β^2 in Fig. 1(A)) based on the x^2-distribution curve are transformed into the fuzzy membership function (represented by $X_{min}(-c_j)$ and $X_{man}(-c_j)$ in Fig. 1(B)), and also maximum value(represented by αi in Fig. 1(A))for the x^2-distribution curve is replaced to the maximum value of fuzzy membership function in terms of the value μ=1.0. In Fig. 1, black-painted area indicates the exclusion part from the reliability area at the determination of fuzzy membership function, and finally, reticulated triangle is to utilize the fuzzy membership function in this system.

2.2 Possibility of Reliability Area according to x^2-distribution Curve

If the independence variables are given as (x_1, x_2, ⋯, x_n), mean of data are expressed to:

$$X = (x_1,\ x_2, \cdots, x_n)/n \tag{1}$$

where n indicates the degree of freedom. Now, let us consider that mean of data, variance, and standard deviation are defined as E(X)=m, var(X)=σ^2/n=ν, std(X)=σ, respectively, the binominal distribution is represented by N(μ,σ^2) as follows:

$$\nu = \sum (x_i - x)^2/n,\ (x = \sum x_i/n) \tag{2}$$

$$x^2 = \sum \{(x_i - x)/\sigma\}^2 \tag{3}$$

As the result, reliability area R_f is equal to:

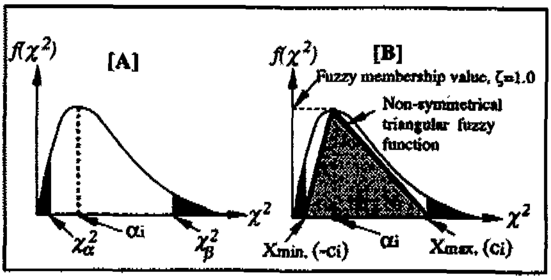

Fig. 1 Reliability Area Based on the x^2-distribution Curve(A) and Triangular Fuzzy Function (B)

$$P\{x_\alpha^2 \le x^2 \le x_\beta^2\} = R_f \qquad (4)$$

where x_α^2 is the lower limit, and x_β^2 is the upper limit based on the reliability area of the x^2-distribution curve. In this case, if we consider the upper(x_β^2) and lower limit(x_α^2) of reliability area given as the x^2-distribution curve, they are represented by the expression

$$1/x_\beta^2 \cdot \sum (x_i - x)^2 \le \sigma^2 \le 1/x_\alpha^2 \cdot \sum (x_i - x)^2 \qquad (5)$$

and utilizing the degree of freedom(n)and variance(ν), Equation(5) can be transformed into:

$$n\nu / x_\beta^2 \le \sigma^2 \le n\nu / x_\alpha^2 \qquad (6)$$

In this system, non-symmetrical triangle obtained from the Equation (6) is finally adopted to the fuzzy membership function for the purpose of accumulating the grinding data-base.

2.3 Application of Fuzzy Membership Function on the Selection of Grinding Wheel

Fig. 2 indicates the knowledge representation on the selection of grain analyzed by the x^2-distribution curve for the purpose of accumulating the grinding database, upper diagram (A) is the characteristics of x^2-distribution curve, and lower diagram(B) is the fuzzy membership function based on the reliability area.

For instance, in the case of the workpiece is bearing steel SUJ2, we know that grains are almostly selected as the A or WA. In this figure, a_i is the center value, and $\pm c_i$ are the possibility width for the triangular fuzzy membership function. Moreover, Fig. 3 indicates the knowledge representation on the

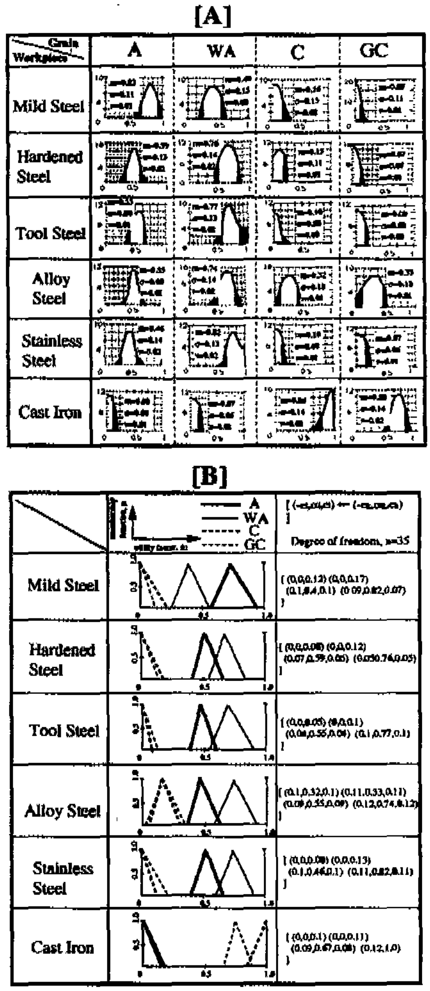

Fig. 2 Analyzed Data Based on the *Enquete* Result for the Grain: (A)Binominal Distribution Curve and (B)Fuzzy Membership Function

grain size in the case of workpiece SUJ2. In Fig. 3, upper part "I"indicates the binominal distribution curve based on the questionnaire, and lower diagram "Ⅱ"represents the fuzzy membership functon. Comparing the fuzzy membership function analyzed from questionnaire result, in the case when the required surface roughness is rough, selectable area of grain size is large, whereas, if surface roughness is more required by the precision grind-

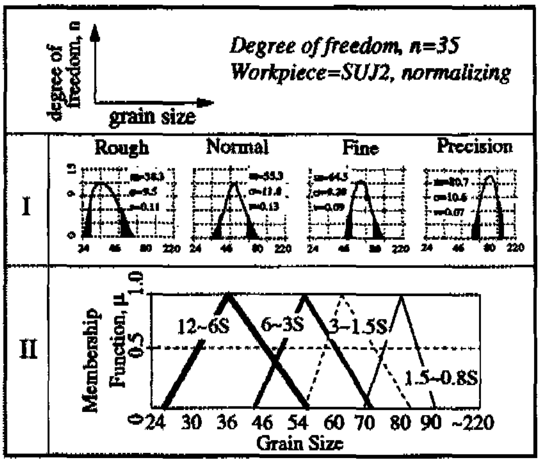

Fig. 3 Analyzed Data Based on the *Enquete* Result for the Grain Size, (I) x^2-distribution Curve, (II) Triangular Fuzzy Membership Function

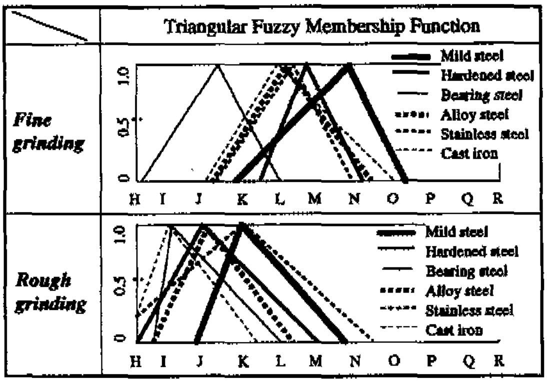

Fig. 4 Analyzed Data Based on the *Enquete* Result for the Grade (x^2-distribution Curve and Fuzzy Membership Function)

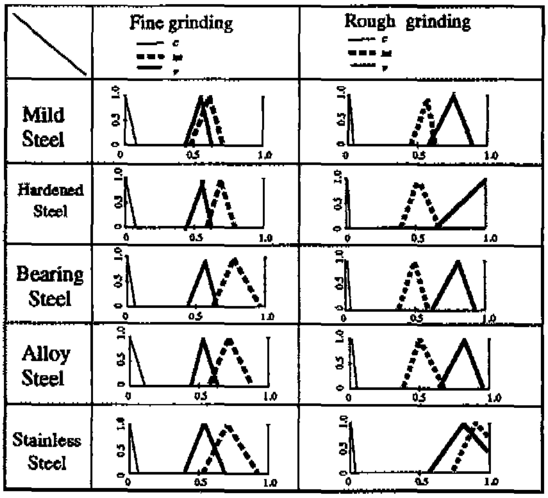

Fig. 5 Knowledge Representation of Structure by the Triangular Fuzzy Membership Function

ing, selectable area of grain size becomes narrower than rough grinding as shown in Fig. 3. That is to say, the required surface roughness is given to the area of maximum value of surface roughness from 12 to 6R_{max}, the selectable area is properly selected to the mesh number from 30 to 54. Thus, the best grain size among the recommended mesh number shown in Fig. 3 is the mesh number 36.

In a similar manner, Fig. 4 and 5 indicate the knowledge representation for the grade and structure with respect to the fuzzy membership function. They are classified into rough and fine grinding so that the grinding efficiency is satified with the material removal rate. Comparing the fuzzy membership function shown in Fig. 4, rough grinding relatively shows a tendency to select the low level grade so as to improve the material removed rates, on the contray, fine grinding becomes a tendency to select the hardened grade so that surface roughness will be satisfied. This means that selection of grade mainly considers both the workpiece hardness and the surface roughness. Alternatively, according to the result of questionnaire shown in Fig. 5, structure is mainly depended upon the workpiece sorts, but porosity of structure becomes a tendency to increase in the case of improving the material removal rates. In Fig. 5, the solid line is the fuzzy membership function on the fine grinding, and the wave line is the rough grinding as defined in the upper boxed diagram.

2.4 Determination of Order of Priority Based on the Fuzzy Multi-decision Making

Research in the selection of grinding wheel has been worked on by K. Umino[5] and K. Subramanian,[6] et al. For example, K. Umino's research in standard of wheel selection considered with the wheel life can only suggest one best optimum grinding wheel, and K. Subramanian's research is worked about the precision production grinding. For their researches are generally reflected upon a single items, it isn't enough to only give the flexibility but to also consider the actual condition of the workshop.

Fuzzy multi-decision making[1,2] should provide more effective results not only complicates the inter-relationship between parameter but also utilizes the uncertain knowledge such as the grinding wheel. Thus, this paper can suggest the order of priority for the selection of grinding wheel considering the lot size and material allowance on each grinding cycle.

Now let's consider a special class of fuzzy numbers, which is suitable for the application of composition of two fuzzy membership function. First we define triangular fuzzy nembers M if its membership function $\mu M{:}R \rightarrow [0,1]$ is equal to:

$$\begin{aligned} \mu M(x) &= 1/(m_i - l_i)x - l_i(m_i - l_i),\ x[l_i, m_i] \\ &\quad 1/(m_i - u_i)x - /u_i(m_i - u_i),\ x[m_i, u_i] \\ &\quad 0,\ otherwise, \end{aligned} \qquad (7)$$

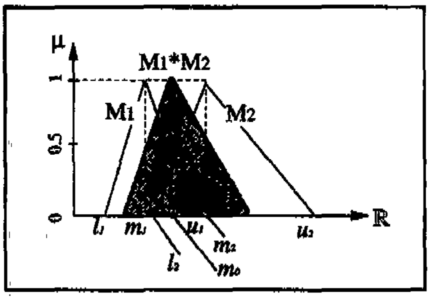

Fig. 6 Relationship between the Two Triangular Fuzzy Function M_1 and M_2 and the Composition $M_1 * M_2$

with $l < m < u$, l and u stand for the lower and upper value of the support of M, respectively, and m for the modal value. The triangular fuzzy membership function, as given by equation,[7] will be denoted by (l, m, u), see Fig. 6. In this figure, m_0 is the value of independence variables on the maximum fuzzy membership value obtained from the fuzzy composition $M_1 * M_2$ of the two fuzzy membership function.

On the other hand, the weight for the wheel components analyzed by the analytic hierarchy process[7] can be obtained as follows:

The weight on the parameter is determined by the eigen-vector by means of comparing the comparative value on each parameter. Now, let's denote the weight on each parameter. If the independence variables are given as $X=\{x_1, x_2, \cdots, x_n\}$, and the dependent variables are denoted as $Y=\{y_1, y_2, \cdots, y_n\}$, weight ω_i each of the grinding wheel can be equal to:

$$\omega_i = \sum^{mk}_{j=1} w_{yj}(x_i) w_z(y_j),\ i = l, \cdots, m_{k+1} \qquad (8)$$

For example, table 1 lists the representation of matrix transfer so as to obtain the weight on grinding wheel by means of analytic hierarchy process. Let's denote five wheel components that A is grain, B is grain size, C is grade, D is structure, and E is bond. Where, a/b listed in Table 1 means the relative weight for the parameter between A and B.

2.5 Determination of Grinding Cycle

Grinding machining time is influenced by the grinding cycle in the case of operating the cylindrical grinding. In this system, grinding cycle is determined by the total grinding machining time considered with lot size of workpiece introducting the model of MEL.[8] This model is given as follow:

$$t_g = t_{wc} + t_d + [t_R + t_S] \cdot l_s + t_c \qquad (9)$$

Table 1 Representation of Matrix Transfer to Obtain Weight

W =

	A	B	C	D	E	Weight
A	1	a/b	a/c	a/d	a/e	x1
B	b/a	1	b/c	b/d	b/e	x2
C	c/a	c/b	1	c/d	c/e	x3
D	d/a	d/b	d/c	1	d/e	x4
E	e/a	e/b	e/c	e/d	1	x5

Where tg is total grinding machining time, t_d is dressing time, t_R and t_s are the grinding machining time for rough and fine grinding, l_s is the lot size of workpiece, and t_{WC} and t_C are set-up time for grinding wheel and workpiece, respectively.

In equation,[9] if only the grinding cycle operates fine grinding, set-up time of grinding wheel t_{WC} and grinding machining time for rough t_R are ignored.

3. DESIGN OF KNOWLEDGE-BASE FOR THE SELECTION OF GRINDING WHEEL

3.1 Design of Grinding Knowledge-base

We suggest that if the cylindrical grinding only deals with the steel, bond among the wheel component to generally utilize the vitrified bonded wheel. Thus, we should only consider the four wheel components of the grain, grain size, grade, and structure. Moreover, in the case of fine grinding, see Table 2, priority of weight is given in order of grain size and grade. On the other hand, priority for other wheel components for rough grinding is given to grain size, grade, and structure. These results are based on the questionniare obtained from a skilful experts who have worked in grinding operations.

Fig. 7 shows the experimental data so that the result of analythic hierarchy process verifies the questionnaire results. If workpiece is SUJ2 and the required surface roughness is given as

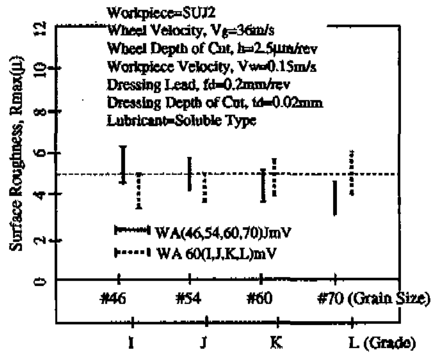

Fig. 7 Experimental Results for the Grain Size and Grade

5μm Rmax, the selectable grain size and grade are recommended as mesh number 46, 54, 60, and 70, and I, J, K, and L as shown in Fig. 3 and 4, respectively. And also Fig. 8 shows the conceptual knowledge architecture for the selection of grinding wheel. The frame based-scheme for the establishment of grinding wheel is designed for class-instance, superclass-subclass, relevance, and group as shown in Fig. 8. For instance, frame-based for describing grain is a specialization of the frame dealing with the more generic concept of grinding wheel, and the frame of grain has a slot whose value is and

Table 2 Comparision of Weight between Rough and Fine Grinding for Grinding Wheel

Rough Grinding				*c.i.=0.072, c.r.=0.064*		
	Grain	Grain Size	Structure	Grade	Bond	Weight
Grain	1	(0.7,0.2)	(1.5,0.3)	(0.5,0.2)	(1.5,0.1)	(0.18,0.04)
Grain Size		1	(1.5,0.5)	(1.5,0.5)	(2.5,0.1)	(0.28,0.07)
Structure			1	(1.5,0.5)	(2.5,0.2)	(0.21,0.06)
Grade				1	(2.5,0.2)	(0.23,0.06)
Bond					1	(0.09,0.01)

Fine Grinding				*c.i.=6.8E-03, c.r.=6.1E-03*		
	Grain	Grain Size	Structure	Grade	Bond	Weight
Grain	1	(0.5,0.2)	(1.0,0.5)	(0.7,0.3)	(1.5,0.2)	(0.16,0.04)
Grain Size		1	(2.5,0.5)	(1.5,0.5)	(2.5,0.2)	(0.33,0.02)
Structure			1	(0.5,0.2)	(1.2,0.5)	(0.14,0.01)
Grade				1	(1.5,0.3)	(0.23,0.04)
Bond					1	(0.12,0.01)

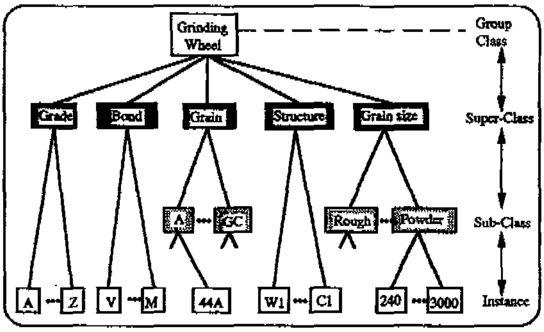

Fig. 8 Hierarchical Structure Utilizing the DataBase on the Grinding Wheel

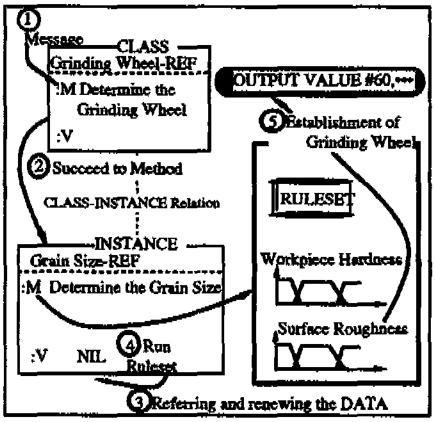

Fig. 9 Decision Flow by the Object-Oriented Paradigm System Establishing the Grinding Wheel

unidirectional link to the grinding wheel.

On the other hand, rule-based scheme according to model of fuzzy multi-decision making is inspired by attempts to mimic the human cognitive process, and it is accomplished by the procedural function defined to "If-Needed-Fact" as listed in Table 3.

Fig. 9 indicates the inference procedure by the procedural function, and it is carried out by the inter-relationship role among the knowledgebase. In a concrete way, selection of grinding wheel utilizing the fuzzy multi-decision making is inferred as follows:

(1) First order the message in frame-based knowledge by the procedural function, matching IF-CLAUSE among the slot accumulated in frame-based knowledge (see process 1, 2).

Table 3 An Example of LISP Program for the Establishment of Grain Size

```
(defruleset grsin_size-result)
  (defrule (grain_size-result rule1 )
    (frame (grain_size-select-R ?f (grain_size ?) ))
    --->
    (bind ?grain_size (get_answer "/data/grainsize "
                                   2000 0.0))
    (call (delete-file " /grainsize "))
    (bind ?x (determine_grain_size ?grain_size) )
    (call (display_result (list " " " " " " ?msg)))
    (call (set grain_size ?x))
    (remove ?f)

 (defrule (grain_size_rule rule 2 )
    (goal (frame (grain_size-select-R ?f (grain_size ?) ))
    --->
    (create grain_size-select-R (grain_size 60)) )
```

(2) According to search of the instance and matchig results, the corresponded slot access the rule-set. By this inference, suggest the order of optimum grinding wheel by according to the priority rule(see process 3-5).

(3) If the matching is not successful done, default value from the frame-based knowledge will be suggested. It may be that the value is the standard condition, In the case of JUJ2 workpiece and 5μm R_{max} surface roughness is given to the mesh number 60 for the grain size as listed in Table 3.

Moreover, Table 3 lists the LISP program represented by the procedural function for the selection of optimum grinding wheel.

3.2 Determination of Priority Rule for the Maximization of Material Removal Rate

We can obtain the selection of optimum grinding wheel according to priority rule described in the suggested equaton.[10] Priority rule is represented by expression:

$$g = \sum(\zeta_i \cdot \omega_i) \tag{10}$$

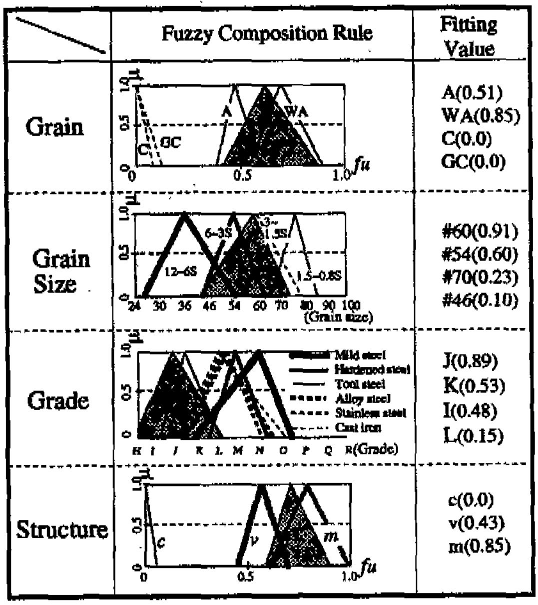

Fig. 10 Concetual Diagram of Fuzzy Composition Rule and it's Fitting Value

where ζ_i is the fitting value, and ω_i is the weight on the wheel components. Among the biggest value produced by obtaining the Equation (10) will be to suggest the optimum grinding wheel, and next most value is the next optimum grinding wheel according to the inferred results by the priority rule.

Furthermore, the determination of the order of priority is accomplished as follows: Firstly, multiplying the weight ω_i by the fitting value ζ_i on each wheel component, and next calculating the sum of them: $\Sigma\omega_i\cdot\zeta_i$, as it were, we denote that it is an order of priority. And then comparing the sum of value calculated by the priority rule, we can be given the order of priority for the selection of grinding wheel.

For instance, let us compare the selection of grinding wheel under constraint conditions which workpiece and the required surface roughness are given SUJ2 and 5μm Rmax, respectively. Fig. 10 shows the conceptual diagram for the decision of fitting value beyond the bond. Fitting value for grade J, K, I, and L are 0.89, 0.53, 0.48, and 0.15, and for structure c, m, and ν are 0.0, 0.85, and 0.43, respectively. Also for grain A, WA, C, and GC are 0.51, 0.85, 0.0, and 0.0, for grain size mesh number 46, 54, 60, and 70 are 0.10, 0.60, 0.91, and 0.23, respectively. Alternatively, as listed in table 2, fine grinding for wheel components grain, grain size, structure, grade, and bond are 0.16, 0.33, 0.14, 0.23, and 0.12, respectively. On the other hand, weight of rough grinding for their value are 0.18, 0.28, 0.21, 0.23 and 0.09, respectively. Thus, the order of optimum grinding is suggested in order of WA60JmV, A60JmV, WA60KmV, and WA54JmV, and so on, and in that order values are 0.77, 0.71, 0.68, and 0.67, respectively as listed in Table 4. Hence the optimum grinding wheel can be selected as WA60JmV.

4. IMPLEMENTATION RESULTS

Let's seggest that the workpiece is SUJ2, the required surface roughness is 5μm R_{max}, and cylindrical plunge cut. In this case, we can obtain the fitting value on the grinding wheel, firstly. That is, the fitting value shown in Figure 10 for grade, J, K, I, and L are 0.89, 0.53, 0.48, and 0.15, and structure c, m, and ν are 0.0, 0.85, and 0.43, and also grain A, WA, C, and GC are 0.51, 0.85, 0.0,

Table 4 Order of Priority for the Grinding Wheel

Parameter / Priority	Wheel	Σg_i (i=1, ⋯, 4)
1	WA60JmV	0.77 (0.14+0.30+0.21+0.12)
2	A60JmV	0.71 (0.08+0.3+0.21+0.12)
3	WA60KmV	0.68 (0.14+0.3+0.12+0.12)
4	WA54JmV	0.67 (0.14+0.2+0.21+0.12)
5	WA60ImV	0.66 (0.14+0.3+0.11+0.11)
6	A60KmV	0.62 (0.08+0.3+0.12+0.12)
7	A60ImV	0.61 (0.08+0.3+0.11+0.12)
8	WA60LmV	0.59 (0.14+0.3+0.03+0.12)
9	WA54ImV	0.57 (0.14+0.2+0.11+0.12)

0.0, respectively. And then we can obtain the result of weight on the rough and fine grinding as listed in Table 2. As the results, the weights on the fine grinding suggests that grain is 0.16, grain size is 0.33, structure is 0.14, grade is 0.23, and bond is 0.0 as listed in Table 2.

Hence, the establishment of grinding wheel based on the fuzzy multi-decision making is performed by utilizing the priority rule represented by the expression $g = \sum(\zeta_i \cdot \omega_i)$.

Utilizing the Equation (10), order of priority for the grain, grain size, grade, and structure can be obtained. That is, WA is 0.14, A is 0.08, C and GC are both 0.0 for the grain, and #54 is 0.20, #60 is 0.30, #70 is 0.05, and #46 is 0.03 for the grain size, and J is 0.21, K is 0.12, I is 0.11, and L is 0.03 for the grade, and also c is 0, m is 0.11, and ν is 0.04 for the structure as listed in Table 4. And also in the case in which workpiece is SUJ2, selection of bond can only selecte the vitrified-bond. As it were, we can ignore the bond when selecting the grinding wheel for the steel.

Therefore, order of priority based on the fuzzy multi-decision making on the grinding wheel is suggested as listed in table 4. That is, optimum grinding wheel on the fine grinding suggests that grain is WA, grain size is mesh number 60, grade is J, structure is m, and bond is vitrified bond V, that is, the selected grinding wheel is WA60JmV.

Fig. 11 indicates the result that carried out by the computer implementation. On the other hand, Fig. 12 indicates the comparision of grinding cycle under the constraint conditions in the case of lot size is 60 numbers and material allowance is 1.12mm. Calculation of workpiece allowance and grinding conditions can be obtained by the suggested model of G.H.Kim,[9] from whose model is suggeted that workpiece allowance for rough and fine are 1.932mm and

```
Please, Select the Grinding Type
1.Surface  2.Cylindrical Plunge  3.Cylindrical Traverse  4.Internal  5.Others
Select Number ==> 2

Please, Input the Required Surface Roughness
Input Value ==> 5  0.2

Please, Select the Classification of Workpiece
1.Mild Steel  2.Hardened Steel  3.Tool Steel  4.Stainless Steel  5.Cast Iron  7.Others
Select Number ==> 3

Please, Select the Heat-Treatment of Workpiece
1.Quenching  2.Normalizing  3.Annealing  4.Hardening  5.Raw Material
Select Number ==> 2

Please, Display the List Inferred Results for Rough Grinding, Just a Moment
[WHEEL  /  Evaluation Value]
1.[WA46HmV/0.89]  2.[WA54HmV/0.75]  3.[WA46ImV/0.71]  4.[WA54ImV/0.65]
5.[WA46JmV/0.63]  6.[A46HmV/0.56]
Select Number ==> 1

Please, Display the List Inferred Results for Fine Grinding, Just a Moment
[WHEEL  /  Evaluation Value]
1.[WA60JmV/0.77]  2.[A60JmV/0.71]  3.[WA60KmV/0.68]  4.[WA54JmV/0.67]
5.[WA60ImV/0.66]  6.[A60KmV/0.62]
Select Number ==> 1

Indicate the Suggested Wheel Selection
[Rough / Fine]
WA46HmV / WA60JmV
```

Fig. 11 Implementation Results for the Optimum Grinding Wheel

8μm, respectively. Moreover, we can also obtain the grinding conditions for rough and fine utilizing that model. Thus, wheel depth of cut h and workpiece velocity V_W for rough grinding are 7.1μm/rev and 0.43m/s, and also fine of their values are 2.3μm/rev and 0.14m/s, respectively as listed in Table 5. Therefore, comparing the results of grinding time we would rather select the two steps process than one if lot size is 27 numbers and over as shown in Fig. 12.

5. CONCLUSIONS

In this study, we constructure the expert system which can support the selection of optimum grinding wheel. The obtained results are as follows:

(1) Utilizing the knowhow and empirical knowledge from skilful experts, we carried out making a questionnaire. On the basis of questionnaire results, fuzzy membership function accumulated in grinding database is represent-

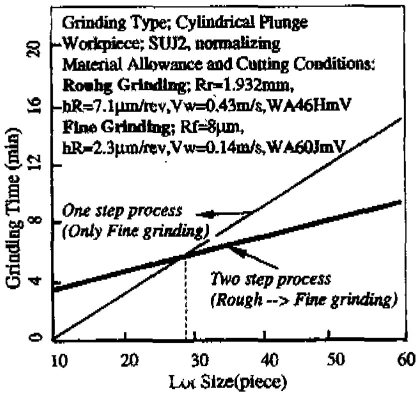

Fig. 12 Comparision between Lot Size and Grinding Time for the Grinding Process

ed as the non-symmetrical triangular form which considered the degree of freedom and properties of data by the x^2-distribution curve.

(2) This system can give the flexibility on the establishment of grinding wheel to utilize the order of priority based on the fuzzy multi-decision making.

(3) Implementation results for the selection of grinding wheel are accorded with the selection of a skiful expert. Therefore, this system is recognized as an effective expert system for the selection of optimum grinding wheel.

Table 5 Optimum Grinding Conditions Suggested in this System

Grinding Type : Cylindrical Plunge Workpiece: SUJ2 ; Material Allowance: 1.12mm Required Surface Roughness, Rmax=5μm Dressing Lead, fd=0.2mm/rev Dressing Depth of Cut, td=0.02mm		
	Rough	Fine
Wheel	WA46HmV	WA60JmV
Workpiece Velocity, Vw(m/s)	0.43	0.14
Depth of Cut, h(μm/rev)	7.1	2.3
Grinding Allowance	1.932mm	8μm

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