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DEVELOPING A KNOWLEDGE-BASED DECISION MAKING SYSTEM TO SELECT THE STEELS OF DIES FOR SHEET-METAL FORMING

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Abstract- Material selection is a problem solving and decison making process. In the selection of die materials, some points are very important. For this reasons, databases are not enough to select the steels of dies for sheet metal in themselves. They do not incorporate data relating to all of the contributing factors needed for quantitive interpretations. To solve the user's problem are requried expertises and knowledge obtained from experts. In this study, a knowledge-based decision making system is introduced which is included the knowledge and experiences of the experts that subject formed from rules and there is a database including the characterictics of die steels. In this system also comprises decision making mechanizm that selects suitable die steels by using user interface.

Keywords - Selection of Die Steels, Knowledge-Based system, Sheet-metal forming

1. INTRODUCTION

The selecting of an appropriate material and then converting it into a useful product with desired shape and properties is a complex process. The first step in any materials selection problem is to define the needs of the product. Without any prior biases as to material or method of manufacture, the engineer should form a clear picture of all of the characteristics necessary for this part to adequately perform its intended function. These requirements fall into three major areas 1) shape or geometry considerations, 2) property requirements, and 3) manufacturing concerns [1]. The area of shape considerations primarily influences selection of the method of manufacture. While such concerns are somewhat obvious, they may be more complex than one might first imagine.

The defining of property requirements is often a far more complex task. Some aspects that should be considered include. Mechanical properties (strength, deformation, fracture, wear resistance etc.), physical properties (electrical, thermal, optical, weight).

Another important area to evaluate is the service environment of the product throughout its life time (operating temperature,

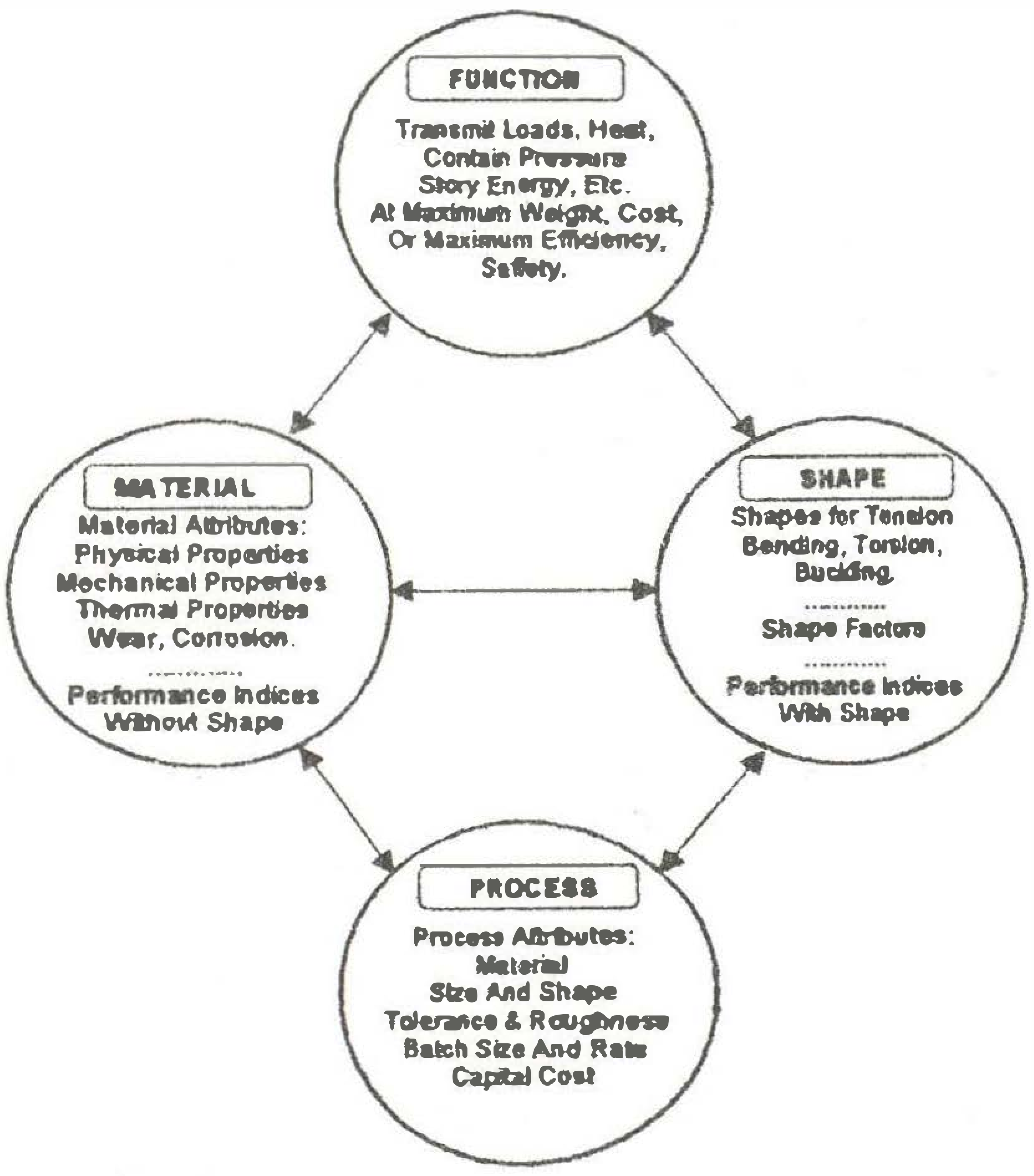

Figure 1. The interaction of Function, Material, Shapeand Process[3].

corrosion, maintenance, service life time etc.) A final area of concern is to determine various factors that would influence method of manufacture (weldability, formability, hardenaability,costability, machinability) [2].

The interaction between function, material , shape and process lie at the heart of the material selection process (Figure 1). Function dictates the choice of material. The Shape is chosen to perform the function using the material. Process is influenced by material properties; by formability, machinability, weldability, heat-treatability and so on. Process obviously interacts with shape - the process determines the shape. The size the precision and, of course, the cost. The interactions are two-way ; specification of shape restricts the choice of materials; so, too, does specification more sophisticated the design, the tigther of process. The the specifications and the greater the interactions[3].

As additional factor to consider, cost is not a service requirement and has not been considered thus far because we have adopted a philosophy that the material must first meet the property requirements to be considered as a candidate. Cost, however, is an important part of the selection process-bath material cost and the cost of fabricating the selected material.

Traditional databases provide a ready means for cost effective storage of large quantities of formatted alphanumeric data with few developer constraints, selective retrieval of data, and in many cases, data manipulation[4]. Databases can readily incorporate data from a variety of resources, be routinely updated, and if not too tightly structured, serve a wide range of proposes and interests. However, they often do not solve the user's problem at hand, or in themselves, create knowledge and all too often, they do not incorporate data relating to all of the contributing factors needed for quantitative interpretations. In contrast, expert systems utilize knowledge bases which are relatively small compared many databases, are considerably more complex in structure, and are by necessity, highly focused in specific domains [5].

Table 1. Differences between databases an knowledge-base

DIFFERANTIATOR	DATABASE	KNOWLEDGEBASE
Collector	Clerk	Expert
Use	Retrieval	Multiple
Type of information	Facts (Data)	Higher level (Rules)
Theoretical requir.	Computational theory	Semantic interpretation

Although expert systems and databases share a common goal of providing user access to data in searchable format and are considered by many as converging technologies, there are many significant differences beyond size and structure one view of the key areas of differentiation are summarized in Table 1 [6].

The provision of information and advice in the selection of materials has been one of the more widely investigated application of computers in engineering [7]. By 1987 over 100 major materials databases had been identified worldwide [8], and considerable effort has been deveted to the development and algorithmic and knowledge - based approaches to selection [9]. Expert systems, using rule-based or object-oriented approcaches among others, that encompass heuristic, knowledge-based approaches to the evaluatýon and specification of materials [10].

2. KNOWLEDGE-BASED SYSTEMS IN MATERIAL SELECTION

The specific approach to problem solving involves understanding involves understanding of interrelations of the scientific principles involved, heuristics derived from the experience of experts, and review of relevant numerical and textual data . The collective knowledge

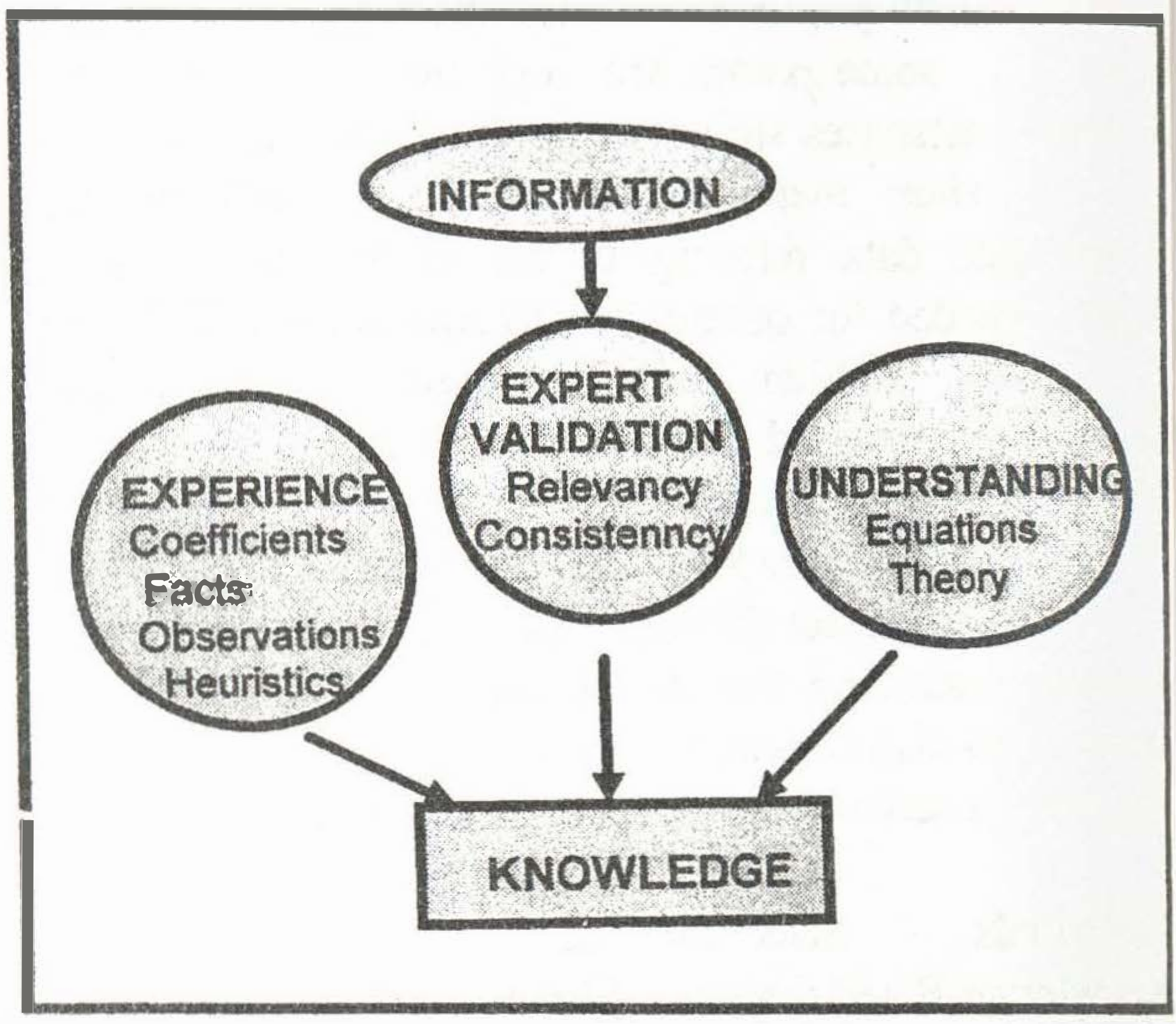

Figure 2. Conversion of information into knowledge [12]

derived in this manner alsobe formulated into rules which, in turn , can be the basis for expert systems which mimic expert consultation and can add important interpretive or advisory interface function to the informational format traditional database. The collective knowledge also can be a resource for formation of algorithms and for inductive reasoning to derive rules from numerical and textual material property data compilations. The derived knowledge can be procedural (how to) or advisory(if-then). Applying these rules requires a sound foundation in domain knowledge both from the application stand point and the nature and the nature of the test methods used the generate property data, the ability to identfy and eliminate personal bias. Rules of this type are quite different from algorithms that may be embeded in databases for calculation of derived values from the data given [11].

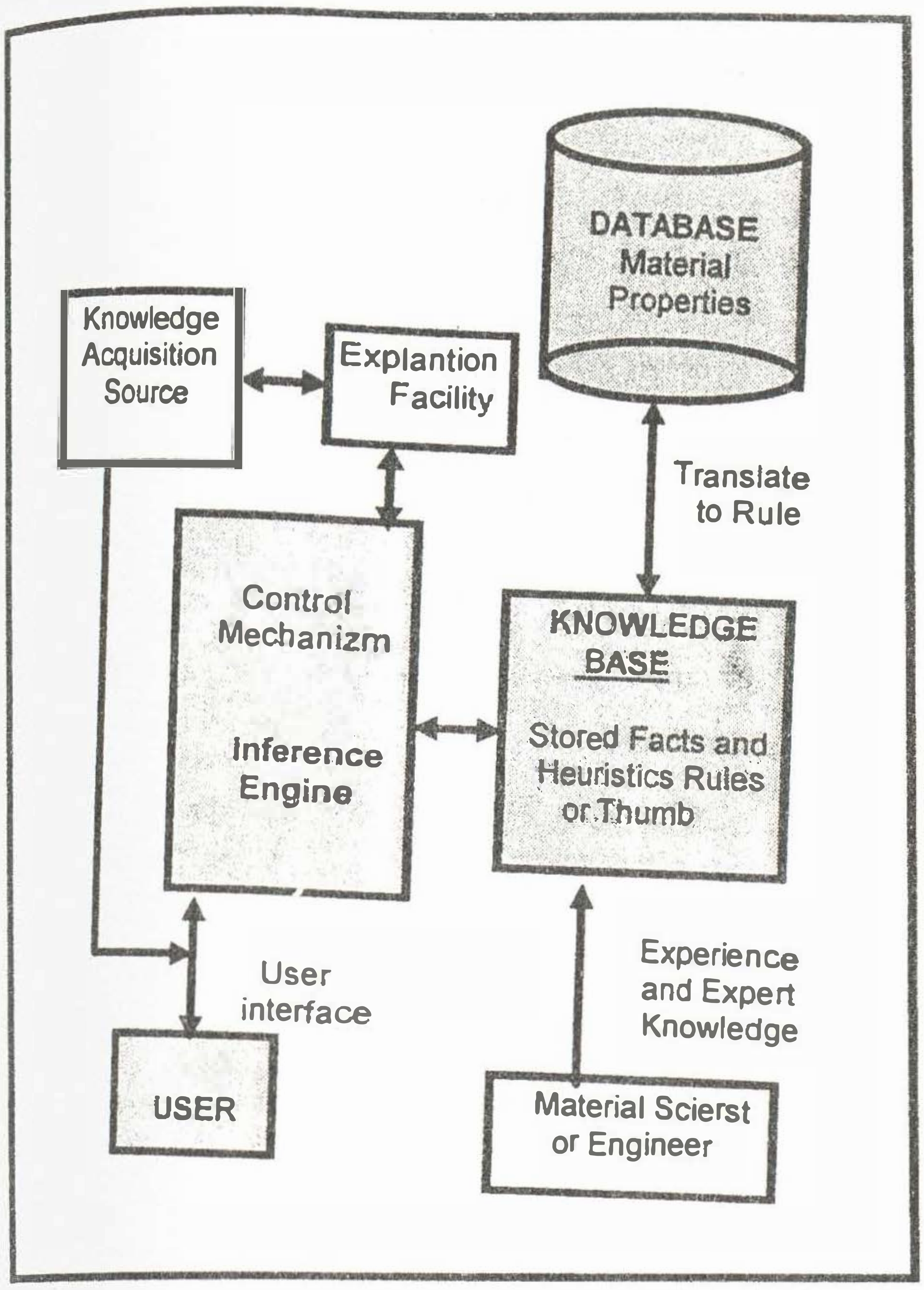

Figure 3. Essential components of a knowledge-based system for material selection

When an experienced material scientist or engineer approaches a problem , he uses his knowledge of both the relevant technologies and the special requriments of the problem.

The resulting knowledge is of greater significance that the general concept of information. The genesis of knowledge from information is shown schematically in Figure 3 [12].

In material selection, knowledge bases are collections of expertise or expert(material scientist or engineer) knowledge that may include anything from basic information (material property nad basic characteristics etc.) about a field of knowledge to guidelines for reasoning about information, in order to make decisions and do tasks. The relation between knowledge-based systems and expert systems is easy to define. A KBS is a system in which the knowledge base is largely distend from the inferencing mechanism or prodedure. Expert system is a general term that may be applied to a wide range of more advanced computer systems described as interactive decision support systems [13]. Figure 4. shows the components of a KBS for material selection: Knowledge base, inference engine and control mechanism, user interface, and computer hardware.

Knowledge-based computer systems have several distinguishing characteristics:

-They contain a knowledge base about specific decision domain or situation that is largely
distinct from the mechanism used to manipulate the knowledge to reach a decision (a process referred to as inferencing).
-They contain an inference engine or inferential reasoning capability, that is largely distinct from the knowledge base and in some respects mimics the way a human decision maker thinks.
-They have a facility that explains their advice or reasoning process, so that can see why and how a conclusion was reached.
-They contain symbolic programming and reasoning capabilities.
-They use IF-THEN rules extensively (but not necessarily exclusively), and so are more readily understandable to nontechnical users.
-They can handle certain, unknown, and conflicting data.
-They often require a high level of development of inducement by a human in expert in their development.

Knowledge-based systems were originally developed using programming languages such as LISP and PROLOG. Today, many other development tools and expert systems shells are available, ranging from development versions of programming languages.

Expert system shells contain such components as inference engine programs, programmed control mechanisms, programmed external software interface routines and capabilities for storing and editing knowledge bases. A shell's user is most often expected to create only the knowledge base. Since shell's require very little (if any) programming expertise, they can be used to develop smaller knowledge-based systems by nontechnical managers with minimal exposure to microcomputers. They are very useful to anyone just learning KBS development.

In material selection, two such programs are known : ICI (EPOS), for the selection of polymers; and a Sandwik program for selection of cutting tools. These are knowledge-based systems dealing with families of essentially similair materials. The other known knowledge base systems which is prepared for material selection are tabulated at Table 2.

Since knowledge-based systems are relatively new and costly to develop, it is usually prudent to develop then in stages, starting with a small prototype of the actual systems.

In developing a prototype, the designer tries to select only the most critical factors and to show only their most basic relationships, in order to test the underlain structure and concept of the system. For this reason, most prototype systems do not (and cannot be expected to) capture all the rich complexities involved in theactual

Table 2. List of some known expert and database systems as software in material selection

SOFTWARE	SUPLIER	FEATURES
CMS: Cambridge Material Selector	Cambridge University Engineering Department	All materials PC format. It implements the selection procedures developed succesive application of up to six selection stages.
PERITUS	Metal System Ltd.	PC format. A data base for metals, polymers and ceramics, aimed at materials and process selection. Selection based on requesting "high", medium or "low" values for given properties rather than numerical values; a display shows the match between candidate materials and the target profile.
CAMPUS :Computer Aided Material Preselection by Uniform Standarts	Hoechts Aktienge	PC format. A collection of four data Hoects, BASF, and Bayer and Hüls thermoplatic polymers, containing information on modulus, viscositiyand thermal properties.Regularly updated, but limited in scope.
EPOS:Engineering Plastics On Screen	ICI Engineering	PC fonnat. The soft general and electrical properties of ICI polymer products, with a search facility.
MATUS: Materials User Service	Materials User Service Engineering Information Company Ltd.	An-on line data bank of UK material suppliers, trade names and properties for metals, polymer ceramics, using data front suppliers catalogues and data sheets.
COPPER SELECT	Copper Development Association Inc	PC format data base of properties and processing information for wrought and cast copper alloys.
PM SELECTOR	MPR Publishing Services Ltd.	A PC based selector powder metallurgical materials for structural use.
PAL: Permabond Adhesives Lacator	Permabond	A knowledge-based, PC system for adhesive select in among Permabond adhesives. An impressive example of an expert system that works.
PLASCAMS	Rubber and Plastics Research Association (RAPRA)	Selection of plastics, thermoplastics and elastomers

situation. That is the function o later more advanced versions of the system. Although they often represent a crude first effort-which is why they are frequently called approximations. Prototype system development is often a useful tool for quickly eliciting knowledge from experts.

The development of a knowledge based system for die steels is explained at the next chapter.

3 - CHARACTERICTICS AND SELECTION OF STEELS FOR SHEET METAL FORMNG DIES

A wide variety formed parts can be produced by sheet metal forming (Figure 4). Sheet metal forming involves punching, bending and stretching. Die sets are often special design of construction and are thus expensive. Some simple shapes can be produced quite economically, however, using standart tooling components [14].

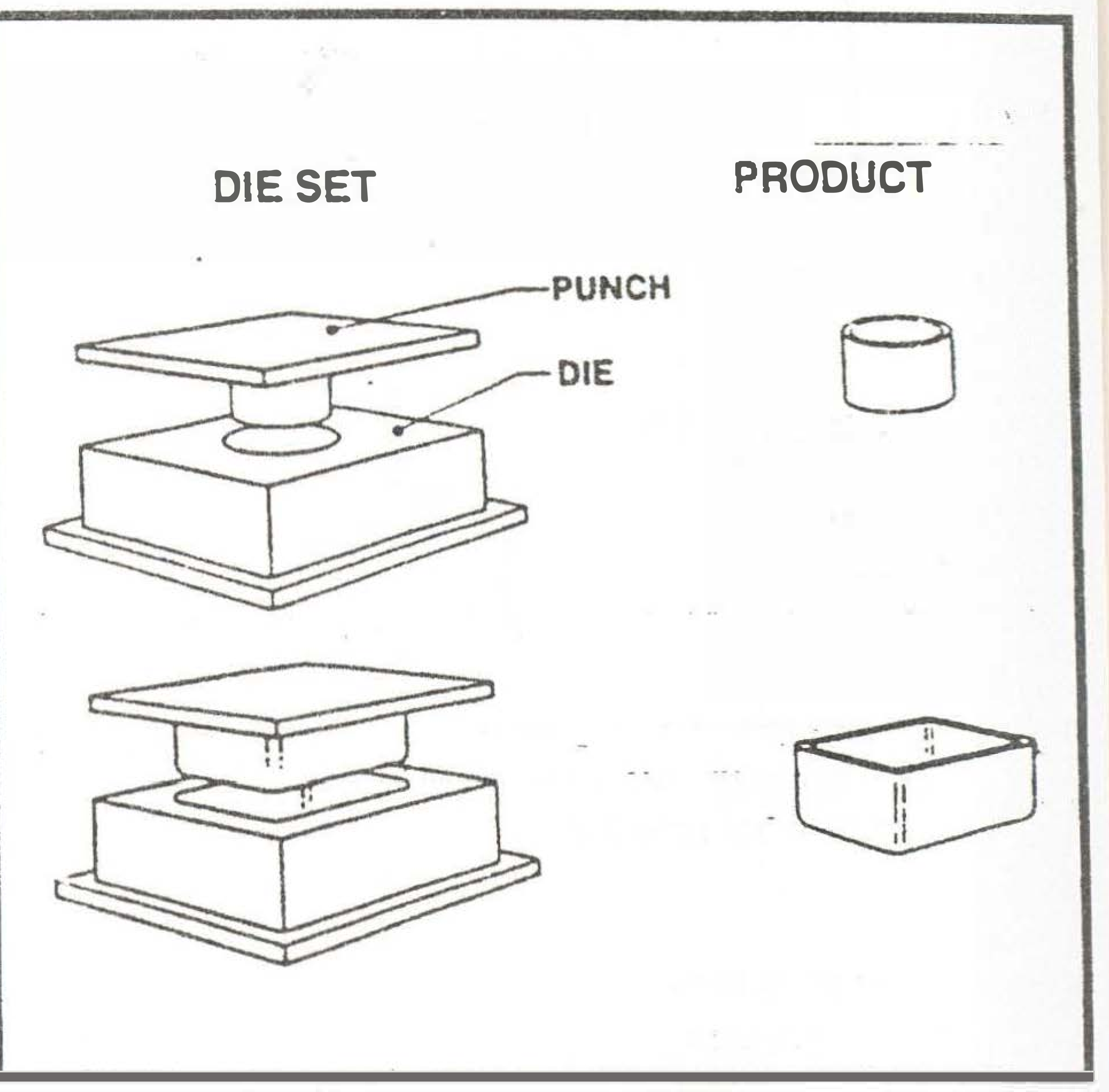

Figure 4. Die set and sample product in sheet metal forming

Sheet metal forming dies are commonly made of tool steel. Carbon stell is not as hard but is tougher and less expensive, therefore, it is used for less severe punch and die applications and for die element s such as the blankholder. Alloy stell is more durable and heat resistant, and cemented carbides are used for applications requiring high wear and abrasive resistance.

Generally the following characteristics are expected from die steels:

a) Machinability
b) Resistance to softening effect of heat
c) Safety in hardening
d) Toughness
e) Wear resistance
f) Adhesivability
g) Non deforming properties
h) Suitable for grinding or sharpening
I) Tempering resistance

However, these characteristics can be changed according to the application and heat treatment. In this study, it is conclude from the experience of die makers the following points are very important in the selection of die material.

1) Kind of property to be produced (low carbon steel, Cu, Al, etc.) The hardness will be about 55-65 R_C hardness for all types of metals. Logically, one can think that the hardness of a die which cuts soft metals such as Cu, Al will be lower. In practice their harnesses will be about the same. Because, machining of the metals is more difficult than hard metals due to higher heat conductivity and adhesion on the cutting surfaces.

2) Hardness and thickness of the produced sample. If the higher hardness will be asked, the harder die will be used The more specimen thickness, the more hardness is required.

Table 3. Comparison of basic characteristics tool and die steels

AISI steel type	Nondeforming properties	Safety in hardening	Toughness	Resistance o softening effect of heat	Wear resistance	Machinability
W1	Low	Fair	Good	Low	Fair	Best
W2	Low	Fair	Good	Low	Fair	Best
O1	Good	Good	Good	Low	Fair	Good
O2	Good	Good	Good	Low	Fair	Good
O6	Good	Good	Good	Low	Fair	Best
A2	Best	Best	Fair	Fair	Good	Fair
A4	Best	Best	Fair	Fair	Good	Fair
A6	Best	Best	Fair	Fair	Good	Fair
A7	Best	Best	Low	Fair	Best	V.Low
A8	Good	Best	Best	Good	Good	Fair
A10	Best	Best	Fair	Fair	Good	Good
D2	Best	Best	Low	Fair	V.Good	Low
D3	Good	Best	Low	Fair	V.Good	Low
D4	Best	Best	Low	Fair	V.Good	Low
D5	Best	Best	Low	Fair	V.Good	Low
D7	Best	Best	Low	Fair	Best	V.Low
S1	Fair	Good	Best	Fair	Fair	Fair
S2	Fair	Good	Best	Faid	Low	Fair
S4	Fair	Good	Best	Fair	Low	Fair
S5	Fair	Good	Best	Fair	Low	Fair
S7	Fair	Good	Best	Fair	Good	Fair
T1	Good	Good	Good	Best	V.Good	Fair
T15	Good	Good	Low	Best	Best	V.Low
M1	Good	Good	Good	Best	V.Good	Fair
M2	Good	Good	Good	Best	V.Good	Fair
M4	Good	Good	Good	Best	V.Good	Fair
L3	Fair	Good	Good	Low	Fair	Good
F2	Faid	Fair	Low	Low	Good	Fair

3) How many workpiece will be pressed. If that number is about 1.200.000, the highest life, if it is about 900.000 the medium life, and finally if it is about 600 000 the lowest life are mentioned. In industry, that life is generally expected about 1 000 000.

4) Types of punches (circular, triangle, square, rectangular). If the punch is circular, its life is larger than the others. Because, in the circular punch, the stress is equally distributed. Three typical punches are shown Figure 5.

5) Types of dies (blanking, bending, drawing etc.), hardness (60 Rc) and heat treatment will be different according to the type of work.

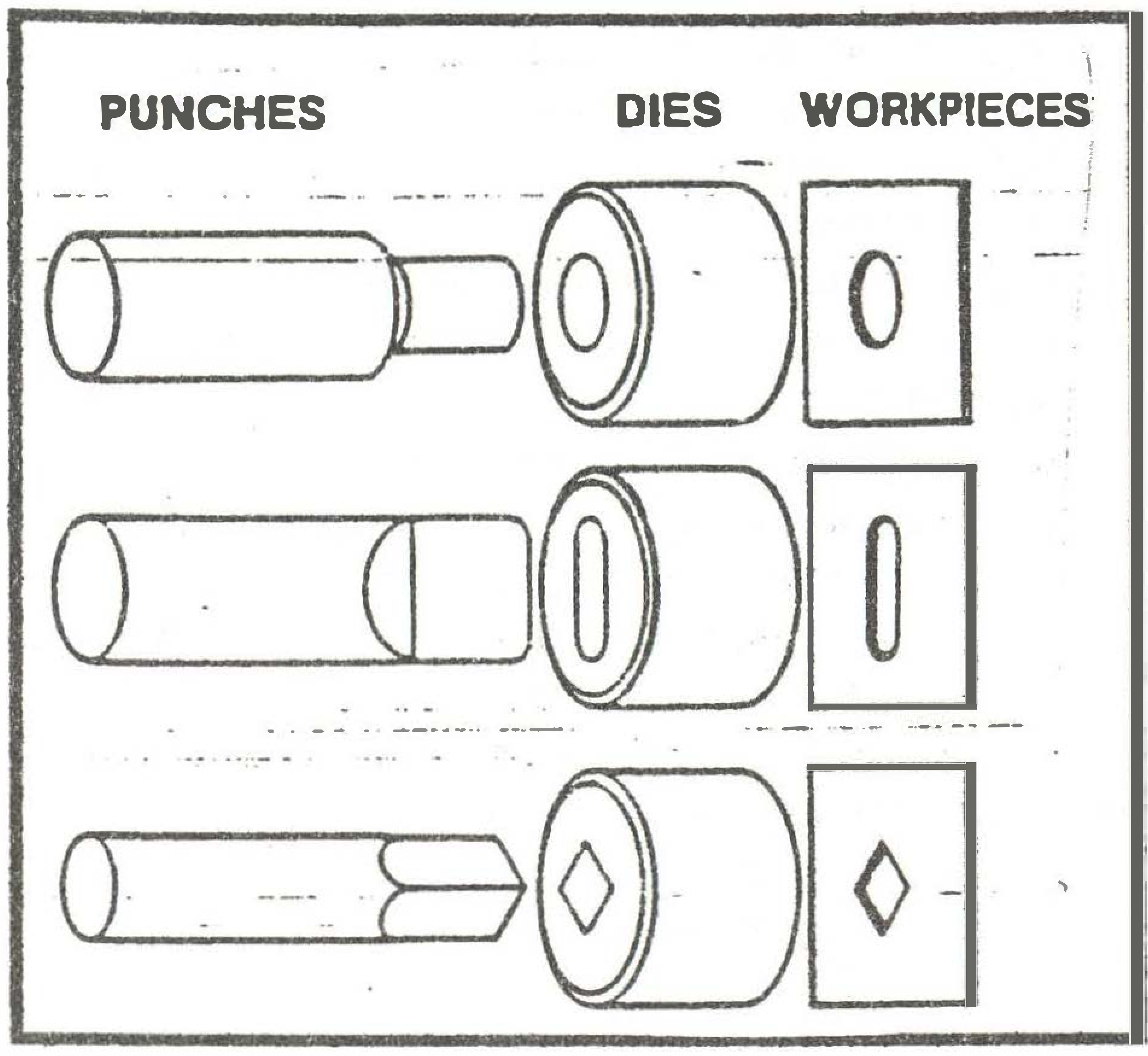

Figure 5. Three typical punches

6) Machining whether before or offer hardening. If there is no electron discharge machine in the factory, first machining than hardening should be done otherwise first hardening than machining due to the fast, precise and easy production in these wire or electrodischarge machines.

The steels listed in Table 3 are applied in the great majority of the metal-stamping operations where tool and die steels are required. The list contains 28 steels, nine of which are widely applied and readily available from almost all tool steel sources. These are steels W1, W2, O1, A2, D2, D4, M2, S1 and S5. The other steels represent slight variations for improved performance in certain instances and their use is sometimes justified because of special considerations. They may have exceptionally heavy usage for certain types of metal-stamping or forming operations [15].

The steels are identified by letter and number symbols. The letter represents the group of the steel involved. Table 3 lists the basic characteristics of the various tool steels listed. A brief statement of the merits of the different groups follows.

W, Water-hardening Tool Steels. W1 and W2 are both readily available and of low cost. W2 contains vanadium and is more uniform in response to heat treatment; it is of a finer grain size with a higher toughness. They are quenched in water or brine.

O, Oil-hardening Tool Steels. Steels O1 and O2 have, for many years, been used in the die-steel industry and are known familiarly as manganese oil-hardening tool steel.

A, Air-hardening Die Steels. The principal air-hardening die steel employed is steel A2. This steel has a minimum movement in hardening and has higher toughness than the oil-hardening die steels, with equal or greater wear resistance.

D, High-carbon High-chromium Die Steels. The principal steels of wide application for long-run dies are steels in this group.

S, Shock-resisting Tool Steels. These steels contain less carbon and have higher toughness. They are employed where heavy cutting or forming operations

T and M, Tungsten and Molybdenum High-Speed Steels. Steels T1 and M2 are equivalent in perfonnance, representing standard high-speed steels which have excellent properties for cold-working dies. They have higher toughness than many of the other die steels, combined with excellent wear resistance.

L, Low-alloy Tool Steels. Of the many low-alloy steels effective as die materials,

F, Finishing Steels. Steel F2 is of very limited use in these field but is occasionally applied where extremely high wear resistance in a water-hardening shallow-hardening steel is desired.

Influence of Heat Treatment on Die Life. Each type of die steel must be handled slightly differently from any other for optimum results. Different temperatures, different heating and cooling rates, and variable tempering procedures must be used. The properties of die steels as developed in heat treatment have an important and direct effect on die life. In general, it may be said that the harder a given die, the longer it will wear, while the softer a die is, the tougher it becomes. For the proper die steel, dies which are wearing out should be made harden for improved life, and dies which are breaking or cracking should be made softer.

4, DEVELOPING A KNOWLEDGE-BASE SELECTION OF DIE STEELS

Knowledge based systems are developed by:

- Analyzing or decomposing, the solution under study and evaluating
- Reformulating or reconceptualizing the decision situation
- Putting the system onto the computer.

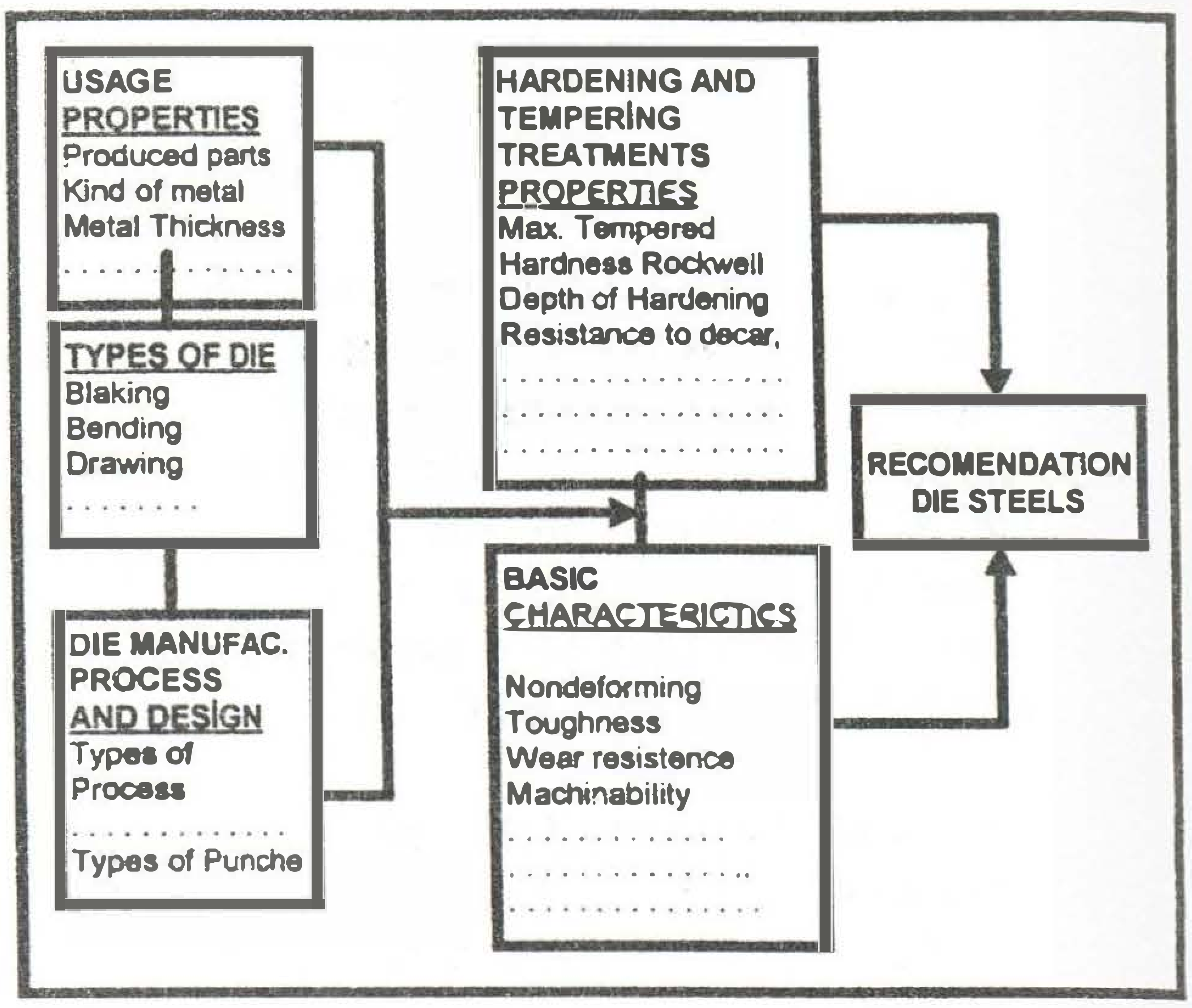

Figure 6. Decision Situation Diagram : Selection of Die Steels

The analyzing phase involves breaking the decision situation down into its smallest components, once the

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RULE --
  IF METAL_TYPE = LCS   OR
     METAL_THICKNESS  = [4 - 6] OR
     PRESS_NUM = HIGH  OR
      DIE_TYPE = BLANKING OR BENDING
  THEN WEAR_RES = BEST;
      . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . .

RULE --
  IF METAL_TYPE = LCS   OR
     METAL_THICKNESS  = [4 - 6] OR
      PRESS_NUM = HIGH  OR
     DIE_TYPE = BLANKING OR BENDING
     PUNCH = CIRCULAR
  THEN NONDEFOR = BEST;
      . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . . . .

RULE --
  IF  NONDEFORMING = GOOD OR BEST  AND
      TOUGHNESS = LOW  AND
      WEAR RESISTANCE = GOOD OR BEST  AND
      MACHINABILITY = LOW
      . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . .
  THEN  DIE STEEL = NUMBER 9
  . . . . . . . . . . . . .
      . . . . . . . . . . . . . . . .
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Figure 7. Sample of "If - Then " rules from knowledge-base for selection of die steels

situation has been selected and defined and the knowledge has been acquired. As the situation is analyzed and evaluated, diagrams are often constructed to provide a more precise picture of the decision or task.

This is variously called ***the situation representation*** phase.

The block diagram in Figure 6. represent a definition of the knowledge needed to make the decision about whether to proceed with selection of die steels. Such a diagram is referred to as a decision situation diagram or model. For example, Figure 7. makes use of a number of decision rules (called heuristics). These can be stated in IF -THEN form, as is shown Figure 7.
As the study of the situation continues, questions are also developed with respect to information the decision maker needs to have about the situation under study. Examples of these are shown at the Figure 8.

```
ASK METAL_TYPE : " What is the produced metal type ?";
CHOICES METAL_TYPE : LCS, Copper, Aluminium, Bronze

ASK METAL_THICKNESS: "How is the produced metal thickness?";
CHOICES METAL_THICKNESS : [0-2], [2-4], [4-6];

ASK PRESS_NUM :" How many work piece will be pressed ?";
RANGE PRESS_NUM : 0, 1,200,000;

ASK PUNCHE :" What is the type of punches ?";
CHOICES PUNCHE : Circular, Triangle, Square;

ASK DIE_TYPE: " What is the type of die ?":
CHOICES DIE_TYPE : Blanking, Bending, Drawing;
.............................................
.............................................
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Figure 8. Sample of Knowledge-base Questions and a User Survey

The type and structure of the reasoning processes involved are defined in progressively greater detail as system development proceeds. This process involves studying the relationships among key situation components. It is an extension of the initial study of knowledge structures within the decision situation being replicated.

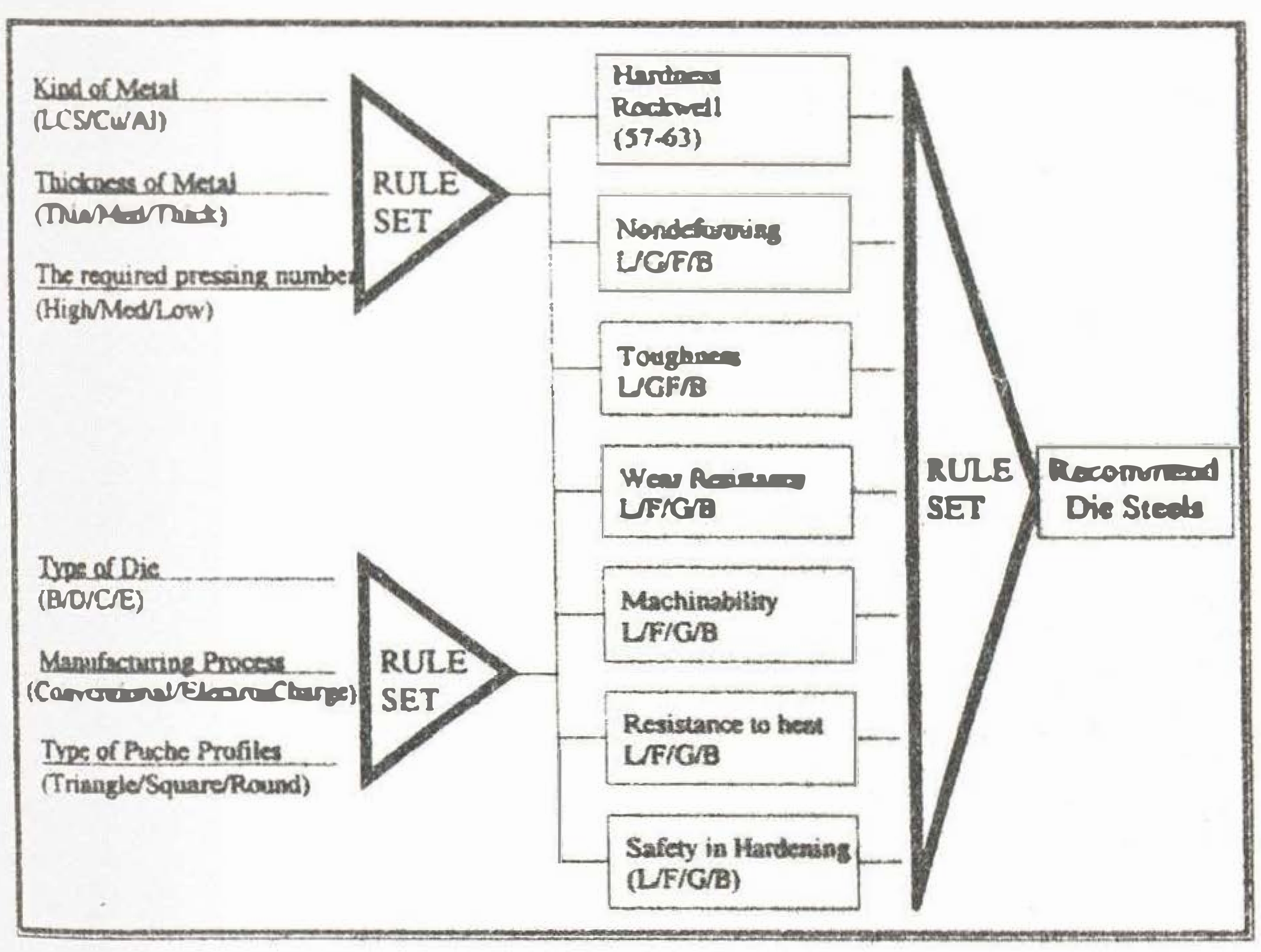

Figure 9. Dependency Diagram for Selection of Die Steels

As an example, in developing the diagram model shown in Figure 9. The system developer might first write a scenario that involves estimating the hardening and basic characteristics of die steels. And then recommends an appropriate steels for user.

CONCLUSION

It is obvious that selecting unsuitable steel for cold work die gives creates negative effects on time and cost of dies. In addition producing dies from very expensive material rises unnecessarily the cost of die. Selecting the suitable die material, dependence on the different factors and the required properties of materials are the business of the expert who knows that particular work. For this reason, using a computer program called expert system which behave as an expert support widely to the user. Therefore, either preparing an expert system program or an expert shell , the most important point is to form the best representing expert knowledge of knowledge bases. In addition, it is more useful for the system to support that knowledge and data bases contain properties of die steels.

REFERENCES

[1] DeGarmo, E.Paul , Materials and Processes in Manufacturing , Sixth Edition, Collier Macmillan Publishers, London 1984.

[2] D. Koshal, Manufacturing Engineer's Reference Book, Butterworth- Heinemann Publ. Com., Oxford, 1993.

[3] Ashby, M.F Material Selection in Mechanical Design. Pergamon Press, Qesirol 1992

[4] Hossain M.K. and Barry T.L., "The Needs of Users and Their Response to Material Databanks", Computeration and networking of Materials Databases, 'ASTM, STP, 1140, Philadelphia, 1992.

[5] Sturock, C.P., "_Computerized Packaging and Transfer Corrosion Engineering Technology ", NACE Corrosion 90, Paper No. 570, National Assocation of Corrosion Engineers, Houston, Texas, 1990.

[6] Freundich, Y., "Knowledge Bases and Databases", IEEE Computer, Vol.23; No.11, pp.51-57, November 1990.

[7] McMahon C. A and Pitt D.J. Hybrid Computer Databases Systems for Materials Engineering. Material & Design Volume 16. Number 1 1995. Page 3-13.

[8] Ulhman, E and Ryden, L, Development of National Materials Database in Sweden, Materials & Design 1987. 8(6), 346-349.

[9] Sangent, P.M., Materials Informatýon for CAD/CAM, Butterworth-Heinemann, 1991.

[10] Hopgood, A., An Inference Mechanizm for Selection, and Its Application to Plymers. Int, J. of. AI in Eng. 1989, 4(4), 197-203.

[11] Anderson D.B., " Expert Systems and Materials Property Databases", Computerization and Networking of Material Databases: Third volume, ASTM STP 1140, Philadelphia, 1992.

[12] Basden, A. and Hines, J. , " Implication of Relation Between Information and Knowledge in Use of Computers to Handle Corrosion Knowledge", British Corrosion Journal, Vol. 21, No.3, 1986, pp. 157-162.

[13] Mockler J.R., Developing knowledge-Based Systems Using an Expert System Shell, Macmillan Publishing Company, Newyork, 1992.

[14] Todd R. H., Allen D.K., Manufacturing Processes Reference Guide, Industrial Press Inc., New York, 1994.

[15] Wilson F.W., Die Design Handbook, Mc Graw Hill Book Company, Newyork, 1985.