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Publisher's version / Version de l'éditeur:

ASTM Special Technical Publication, 1254, pp. 71-81, 1994-06

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NRCC-38440

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A version of this document is published in / Une version de ce document se trouve dans:
Building Envelope Performance and Durability, IRC Technical Seminar, Held in 11 Cities
across Canada, February through March 1995, pp. 71-81

National Research
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de recherches Canada

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Sealant Selection Using an Expert System

REFERENCE: Lacasse, M. A., Beznacuk, L. M., and Gowri, K., "Sealant Selection Using an Expert System," *Science and Technology of Building Seals, Sealants, Glazing, and Waterproofing: 3rd Volume, ASTM STP 1254*, James C. Myers, Ed., American Society for Testing and Materials, Philadelphia, PA 1994, pp. 71-81.

ABSTRACT: Sealants used on the exterior of the building envelope must fulfill their performance requirements in a very demanding location within the enclosure system, namely joints. For this reason they tend to be prone to premature failure if not properly matched to the surrounding conditions and materials. Sealant selection is a complex and time-consuming process involving the simultaneous consideration of a multitude of performance criteria. A systematic approach that enables a more comprehensive consideration of the various criteria is therefore important. The prototype expert systems are an attempt to do this. In this paper, a review is made of the main features of the initial prototype sealant selection expert system, including a brief discussion of the decision making process, the assumptions and inherent limitations of the system. Of particular interest in this paper is a description of the advanced prototype system being developed which provides significant improvements over the initial system. This advanced system will include an extensive database from which the following information can be extracted: weather data, sealant performance data, and graphic details database on sealant application.

KEYWORDS: sealant, sealant selection, expert system, building joint design

Sealants that are used on the outside of the building envelope must fulfill their performance requirements in one of most demanding locations within the enclosure system, namely joints. For this reason they are prone to premature failure if not properly matched to the surrounding conditions and materials. Sealant selection is a complex and time-consuming process involving the simultaneous consideration of a multitude of performance criteria. More often than not, one or more factor is likely to be left out in the selection process. A systematic approach that enables a more comprehensive and ready consideration of the various criteria is therefore important.

Several guides for sealant selection intending to provide such a systematic approach exist [1-5]. These efforts have been produced by sealant manufacturers, related technical associations, government bodies, as well as researchers and experts in the field. An early effort was made to review and combine this material to produce a comprehensive guide to sealant selection [6]. The development of this manual helped establish that the choice of an appropriate sealant, from the point of view of the architect, engineer, or specifier, needed to be based not only on a consideration of potential movement at the joint, but also, on other equally important factors known to affect sealant long-term durability.

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These early efforts demonstrate that no adequate methods exist, at least not by standard test methods, to qualify the life expectancy of sealants based on such factors as, resistance to extension-compression cycling or resistance to ultraviolet radiation. Furthermore, the interrelationship of the two variables mentioned has not yet been made clear, making it difficult to establish the life expectancy of various products and hence the consequences of a particular choice of sealant.

Choosing a sealant is not a trivial matter in light of the fact that despite the low cost of installing sealants in relation to the overall cost of a building, the cost of sealant replacement and repair of damage may be considerably more than that of the installation costs. It is evident that a knowledge of the importance of these factors to the durability of a sealant is of prime importance, however, the only means that exists at this time to obtain such information, is through consultation with an expert practitioner in the domain. That is to say, presently an informed decision is based on information acquired through a practice in the trade.

Knowledge Based Expert Systems

Knowledge based expert systems (KBES) are particularly well suited to the incorporation of heuristic knowledge and this is one of the characteristics that distinguishes it from a conventional (algorithmic) computer program [7-10]. The use and development of KBES in engineering has increased steadily in the past fifteen years because they provide advantages in solving problems that require cost effective analysis in a timely manner [7]. Furthermore, they can readily accommodate the type of heuristic information in the form of rules of thumb, assumptions, simplifications based on experience, and related expert information that can not be processed by conventional means [8]. To some extent, they emulate the decision making process of an expert in the domain.

Hence, KBES are interactive computer programs that contain heuristic knowledge, in the form of rules, as well as factual knowledge in a particular domain (that is, domain knowledge) and perform tasks normally done by an expert [7,8]. A schematic of the computer "architecture" that typifies KBES is shown in Fig. 1. The focus in KBES is on knowledge rather than data, as in conventional programs, and emphasis is placed on processing information ("domain" knowledge) by an inference mechanism ("control" knowledge) that controls the manner in which the domain knowledge is applied. Thus "domain" knowledge and "control" knowledge are implemented separately allowing various facilities (that is, explanation and knowledge acquisition facilities) to display, search or modify the domain knowledge base without affecting the manner in which this knowledge is processed by control knowledge (that is, inference "engine"). The control knowledge is also used to modify and expand the context, in which the context contains information about the problem currently being solved. Another feature of KBES programs is that there is some explanation facility to convey to the user the inference actually used in arriving at a solution to a problem. This makes such type of systems particularly useful in the training of non-experts in an experts particular domain.

Expert systems have been used in a variety of engineering applications [7,9,10]. For example, in civil engineering, problem solving programs have been developed in the areas of structural analysis and design, code checking, as well as in the areas of geotechnical and transportation engineering and construction management [7,9]. More recently, emphasis has been placed on the development of systems for the inspection, repair and maintenance of various materials or structures [10] and expert systems are increasingly being used in a number of related fields as was demonstrated at a recent congress of the CIB [11].

In this paper, a review is made of the main features of the initial prototype sealant selection expert system [12,13], including a brief discussion of the system architecture, the decision making process, and the assumptions and inherent limitations of the system. An example is

FIG. 1—Computer architecture of an expert system [7].

provided to demonstrate the potential usefulness of the prototype system and to indicate the input and output formats used in this program. Of particular interest in this review is a description of the advance prototype system that provides notable improvements over the initial system. This advanced system will include an extensive database from which the following information can be extracted: weather data, sealant performance data, and a graphic details database on sealant application.

Initial Prototype System

The initial prototype expert system was developed from the Sealant Selection Manual [6] as a rudimentary tool for simplifying the selection of a sealant specifically for the purpose of sealing joints on the exterior walls of buildings. It assists in the selection of one or more of the following nine sealants: butyl, skinning; butyl, non-skinning; hypalon; acrylic; polysulphide, 2-part; polysulphide, 1-part; polyurethane, 2-part; polyurethane, 1-part; silicone.

Through a user friendly interface, the system uses a series of questions to prompt the user to provide contextual information, such as input design conditions and sealant performance criteria. Figure 2 shows an example of user input for specifying the surface color of cladding. A list of choices is provided to the user along with a brief description of the performance parameter, however, a separate explanation ("help") facility is not provided. The performance criteria included in the prototype system are: life expectancy, exterior service temperature limits, cladding material, cladding surface color, cladding heat capacity, joint movement, cladding coefficient of thermal expansion, sealant resilience, period or frequency of extension/compression cycling, sealant color range, sealant surface dirt pickup, puncture and tear resistance, surface preparation, surface primer, and tack-free time.

Surface Colour of Cladding

The surface colour of cladding material has an effect on its surface temperature. Please select the surface colour or tone which is closest to the colour under consideration. For example, a dark clay brick would be considered DARK GREY, while a light clay brick would be considered LIGHT GERY.

Surface tone

- ☒ Aluminum
- ☐ Copper
- ☐ Black
- ☐ White
- ☐ Dark Grey
- ☐ Light Grey

FIG. 2—Example of user input for the initial prototype system.

Several parameters do not have to be input by the user, as the knowledge base calculates the values from other related criteria given by the user. These calculated parameters are: maximum and minimum surface temperatures, effective panel lengths, suggested joint widths, calculated and maximum joint movement, and UV resistance required. The values of these parameters are summarized in an output form named "intermediate values." An example is shown in Fig. 3.

Intermediate Values

Minimum Surface Temperature.....	-38.0 degree
Maximum Surface Temperature.....	45.0 degree
Effective Panel Length.....	1253.0 mm
Suggested Joint Width.....	13.0 mm
Calculated Joint Movement.....	9.0 %
Maximum Joint Movement.....	9.0 %
UV Resistance Required.....	Excellent

FIG. 3—Example screen for intermediate values.

The inference mechanism used in this program determines the relative performance of any of the nine sealants within the system. It assigns a rating (performance factor—PF) for each category of criteria ranging from 0 to 1. This rating is related to the degree to which the sealant performs for a given criteria (e.g., low performance, PF = 0.1; high performance, PF = 0.9 to 1.0). In the selection process, all sealants are initially assigned a value of 100 and thereafter this value is reduced in relation to the sealant's capacity to meet specific performance criteria. In other words, initial values are multiplied by the various factors, and once the system passes through all the required criteria, the cumulative total of all the ratings for each sealant is calculated by the system and presented to the user. This is essentially a process of elimination, as sealants which do not achieve the user's required level of performance are either eliminated or are assigned a relatively low performance factor.

Based on this process of elimination, the system classifies the information and presents the user with a list of recommendations on sealant selection, as shown in Fig. 4. Aspects related to relative costs are kept separate such that a selection can be made based solely on performance characteristics, or based on a combination of both performance characteristics as well as the relative cost of the sealant. In order to assist the user in reviewing the input data, an input summary screen, as shown in Fig. 5, is provided.

Programming Assumptions

Certain assumptions and simplifications were made to limit the amount of input data required from the user, which were:

- i. The environmental conditions around the building under consideration are assumed to be uniform across the entire surface of the building envelope.

RATING OF SEALANTS

According to your input, the following sealants have been rated, and their associated percentages indicate the level of recommendation (a value of 100 is the highest recommendation).

	Not Considering Cost	Considering Cost
Butyl, Skinning.....	0	0
Butyl, Non-skinning.....	0	0
Hypalon.....	4	4
Acrylic.....	0	0
Polysulfide, 2-part.....	7	4
Polysulfide, 1-part.....	19	14
Polyurethane, 2-part.....	32	19
Polyurethane, 1-part.....	34	23
Silicone.....	23	13

FIG. 4—Example screen for recommendations.

Input Parameters:

Life Expectancy.....	20 years
Minimum Temperature.....	-15 degree Celcius
Maximum Temperature.....	30 degree Celcius
Cladding Material.....	Concrete
Surface Colour.....	Light Grey
Material is Low Heat Capacity.....	False
Maximum Panel Dimension.....	1250 mm
Coeff. of Linear Expansion.....	1.2e-005
Resiliency Required.....	High
Joint Cycling.....	High
Colour Range.....	Unlimited
Dirt Pickup.....	None
Tear Resistance Required.....	Excellent
Surface Preparation Quality.....	High quality
Primer Use.....	No preference
Tack Free Time in days.....	2

FIG. 5—Example screen for input parameters.

- ii. Cladding differential movement due to moisture absorption or drying is disregarded as well as any effects due to structural frame movement brought about by loading conditions.
- iii. Minimum joint widths are suggested according to panel sizes, following the general rule that the larger the cladding panel the wider the joint should be.
- iv. The required ultraviolet (UV) resistance depends only on its required service life. The required UV resistance is assigned, within the program, to service life expectancy accordingly.
- v. The coefficient of thermal expansion for four typical cladding materials (masonry, concrete, aluminum, and copper) is given specific values by the system.
- vi. Certain performance factors are more critical to overall sealant performance and service life than others. In this respect, less critical performance factors were assigned higher ratings (that is, 0.8 to 1.0) and more critical factors were assigned the entire range of ratings (that is, 0.1 to 1.0).

Program Limitations

Although this initial prototype expert system is quite comprehensive in terms of the performance criteria and design aspects it covers, there are a few limitations to the system in its present form:

- i. The system is limited to making recommendations with respect to the nine generic based sealants only.

- ii. Recommendations are made for an appropriate sealant choice in a given environment on the basis of the rating system. The performance factors for each sealant are specific to the present program and cannot, as yet, be altered during a consultation session.
- iii. The system does not accommodate for joint widths other than the minimum ones recommended by the system (13 mm for cladding panels less than 3000 mm; 16 mm for larger panels). The only accommodation that the system does make is that it recalculates the minimum joint width to limit the maximum joint movement to 25% of the joint width.
- iv. The system assumes that a sealant will perform the same when applied to different types of cladding (for example sealants applied to various types of aluminum cladding will perform the same).
- v. The system does not allow changing the level of significance of the performance factors.

Advanced Prototype System

The consideration of several performance criteria and ranking of the generic sealants demonstrated by the initial prototype system shows the feasibility and advantages of the expert system approach. However, the initial prototype has a limited scope in terms of the knowledge base, user-interface features and sealant product information. In order to overcome these limitations, an advanced prototype system is currently being developed. The major difference between the advanced and initial prototypes will be the identification and classification of sealant products and performance data in a modular form for easier representation and efficient implementation. A schematic of the new expert system architecture is shown in Fig. 6. The following modules can be identified:

- i. User-interface
- ii. Inference mechanism (control)

Sealant Selection Expert System - Schematic

FIG. 6—Proposed expert system architecture for advanced prototype.

- iii. Knowledge-base (domain knowledge)
- iv. Database (weather data, sealant properties and graphic details)

User-Interface

The user-interface of the advanced system will consist of simplified input forms, context sensitive help, explanation and reasoning to enable the user to specify preferences and exercise control over the selection process. The user input data, defining the design context, will be minimized to three input forms: (i) building parameters, (ii) desired sealant characteristics and (iii) preferences on sealant performance characteristics. The building parameters would include the location, building type, joint type, cladding material, surface color and length of panels. Many of the sealant selection criteria can be established knowing the building parameters and deriving the appropriate information from the knowledge base and database. For example, the location of a building can be used to obtain the minimum design temperatures, degree days and relative humidity. Similarly, the joint type and cladding material data can be used to select certain generic sealant categories based on the movement capability of the sealant. The desired sealant characteristics would include life expectancy, requirements for priming, tack free time, puncture and tear resistance, etc. These are essentially a combination of quantitative and qualitative criteria which will be used as a basis to search the sealant database for appropriate products. Finally, the user can specify preference on performance characteristics such as the cost and color range.

Inference Mechanism

The control knowledge of the proposed system attempts to interface the user-input information to the knowledge base and database. A complete description of the design context is established by the inference mechanism by determining the nature of characteristics and deriving their values appropriately. For example the calculation of surface temperatures would involve obtaining user input of building location, retrieving design temperatures from the database, and accessing the knowledge base for calculation procedures. Once all the values are established, the inference mechanism would attempt to match these values with a database template to identify appropriate sealant products. Finally, sealant products will be ranked based on user specified preferences. The inference mechanism will be implemented to follow a systematic approach which can be reasoned and explained to the user.

Knowledge-base

The knowledge base provides rules-of-thumb and calculation procedures to establish quantitative performance requirements for sealant selection. For example, material compatibility information such as adhesion characteristics will be used to eliminate or select a particular generic category of sealants. In addition, the knowledge base would contain procedures to calculate the surface temperatures, and maximum joint movement. The knowledge base information will be extracted from interviews with experts, design manuals [14-16] and other research literature [17,18].

Database

The database of the proposed system consists of three major sub-components. The first is a weather database containing design temperatures, degree days, relative humidity and possibly of weather information relevant to assessing the performance of sealants. For the most part, this data may be obtained from the supplement to the National Building Code of Canada [19].

The second sub-component is the sealant product performance data which can be classified as quantitative, qualitative, or descriptive in nature. Some of this data is readily available from sealant manufacturers, whereas other qualitative and descriptive information may be obtained from experts and design manuals. The sealant products database will be organized in two levels representing generic and specific products. The first level will identify the generic sealant categories and characteristics. The second level will consist of specific sealant products with their associated technical performance data. Figure 7 shows a typical database structure of the proposed implementation. The quantitative performance data includes sealant costs as well as relevant sealant technical properties such as movement capability, installation and surface temperature ranges and curing time. These are numerical values, which, in certain cases, are based on standard test methods and are often provided by manufacturers. The qualitative performance characteristics include the names of compatible materials, available colors and surface preparation quality. Finally, descriptive performance characteristics are provided for explanation and reasoning purposes. This knowledge will be used to justify the selection or elimination of specific categories or products.

The final sub-component of the database is graphic details of sealant installation. It is often critical to provide the sealant installation sequences and construction details. Such information will be available for each sealant product and other general guidelines will be provided as well. In the advanced prototype, it is proposed to investigate the feasibility of incorporating such graphic information as part of sealant selection recommendations which the user can either view or print to assist in specification writing.

In order to implement the advanced prototype, many expert system development tools available in the personal computer environment have been reviewed. Level 5 Object, operating

FIG. 7—Proposed database structure for advanced prototype.

under the MS-Windows [20] environment, has been chosen as the best suited to implement the proposed system. User-input screens, database structure and knowledge acquisition are presently in the process of being completed. Field testing and validation of the system will then be undertaken.

Summary

Expert systems for assisting in the selection of sealants have been developed with the purpose of providing a comprehensive review of various performance criteria such that the task of choosing an appropriate sealant is both less time consuming and is based on a knowledge of factors influencing the choice of a particular product. The development of the initial prototype system was useful in demonstrating the feasibility and advantages of using the expert system approach to perform this often complex task. However, the initial system has a limited scope in terms of knowledge base, user interface features and sealant product information. The advanced prototype system, currently under development, affords significant improvements to the initial system and will offer a comprehensive treatment of joint design and sealant selection based on information obtained from current specification guides, published expert advice, as well as research literature. The proposed advanced system will provide an extended database from which weather data, sealant performance data and graphical details of typical sealant application and installation methods can be obtained.

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