Linking Customer Needs of Refractory Suppliers with Technological Requirements on the Refractories

J. Fruhstorfer, L. Schöttler, Chr. G. Aneziris

Although the suppliers and developers of refractories often know what is expected of their product, in many cases the details of what requirement is how important are unknown and difficult to estimate. A tool to link customer needs with technological requirements is a method called House of Quality (HOQ). In this study a planning matrix-HOQ for refractories applied in steel ingot casting is developed. Of the technological requirements thermal shock, erosion, impact and corrosion resistance, the thermal shock resistance has the highest impact on the application behaviour. Nevertheless, by optimising the corrosion resistance good results can be obtained faster. Thus, the method proved to be able to identify not only importances of the requirements but also an order in which to address their development.

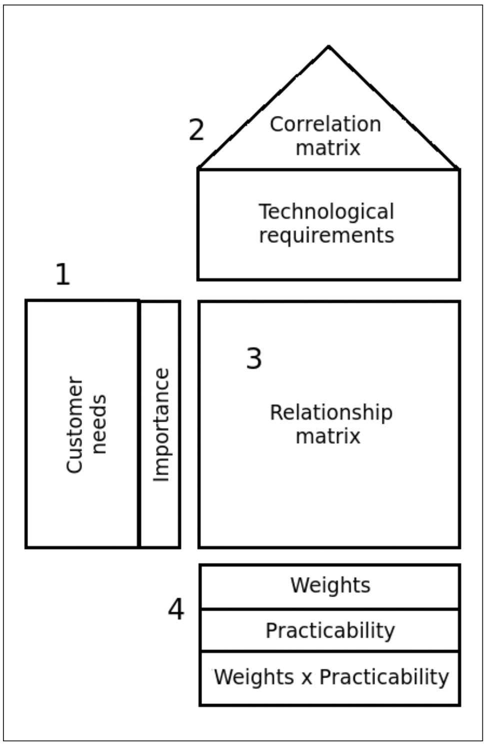

Fig. 1 **Schema of the applied House of Quality matrix including the methodological steps 1 to 4 of its preparation**

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1 Introduction

Global economic competition obliges companies to meet continuously specific requirements of actual and potential customers [1]. Improving quality and productivity ensures to stay competitive [2] but often in the different professions of the customers and suppliers different terms are used to describe the requirements.

Although the suppliers often know what is expected of their product, in many cases the details of what requirement is how important are unknown and difficult to estimate. Like for development, the same applies for research topics – often their impact is difficult to predict.

A tool to link customer requirements with technical and technological characteristics is Quality Function Deployment (QFD) [2–4]. It is comprised as a tool in total quality management. To establish the links or relationships, QFD employs matrices based on the standard "what-how" matrix which is called House of Quality (HOQ) due to its shape [5]. In general, the planning matrix links the customer requirements with technical requirements, the design matrix the technical requirements with the component characteristics, the operating matrix the component characteristics with the process steps and the control matrix the process steps with operational steps [1]. Establishing QFD would give the possibility to cope not only with increasing quality demands but can help to translate, categorize and prioritize customer needs [1].

In the present study, a planning matrix for refractories will be developed on the example of products for application in steel ingot casting.

2 Methodology

In this study, a planning matrix in the form of a House of Quality (HOQ) will be developed which links the customer needs in the steel ingot casting process with the technological requirements of refractories. Fig. 1 shows schematically the different parts of the HOQ applied in this study, which will be discussed followingly step by step.

The first step in preparing a HOQ is to identify the customer needs of number N. Then they have to be prioritized and be given an adjusted importance $i_{customer\ need} = i_n$ with n running from 1 to N [1]. The importance will be set from 1 for low importance to 5 for high importance.

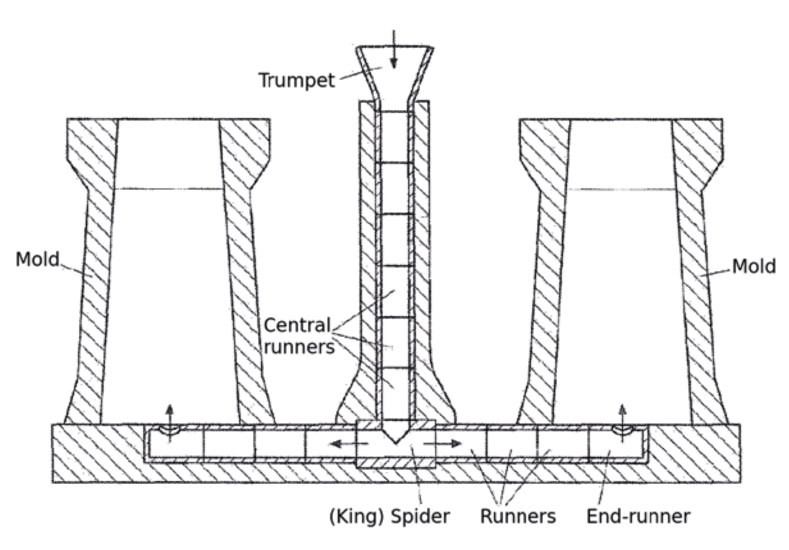


Fig. 2 Exemplary refractory pipe system used in bottom teemed steel ingot casting after Ritter et al. [6, Fig. 1]

The second step comprises to describe the technological requirements R_m (with m marking the different requirements) and their correlations or interactions among one another [1]. This correlation or interaction matrix, the "roof matrix", gives the HOQ its name [5].

Thirdly, the relationship matrix is estimated. It is evaluated subjectively, to what degree which technological requirement impacts which customer need [1]. For the evaluation, direct relationships are evaluated as well as the interactions with other properties from the "roof matrix". Strong relationships $r_{n,m}$ are marked 9, medium ones 3 and weak relationships 1. If no relationship is apparent, the cell is left empty.

The fourth step is to calculate the weights. They are one of the main output of the HOQ [1] and are determined by eq. 1 for every technological requirement marked by *m*.

$$weight_m = \sum_{n=1}^{N} i_n \cdot r_{n,m} \qquad (1)$$

Furthermore, the practicability is evaluated. The practicability describes how easy (value 5) or difficult (value 1) a technological requirement is to adjust. The product of weights and practicabilities by column gives ultimately a priority list in which order the requirements should be investigated, starting with the one which has the highest impact and is the easiest to adjust [3, 4].

3 Results and discussion

In line with the methodology, a House of Quality will be applied to the example of refractory products for application in steel ingot casting. Firstly, the customer needs will be analysed, then the technological requirements described and ultimately the House of Quality will be developed.

3.1 Customer needs and importances

The customer wants the refractories to function throughout the complete steel ingot casting process.

During steel ingot casting, the hot steel is poured into and then flowing through a non-preheated refractory pipe system, generally referred to as hollowware (Fig. 2) [6, 7]. The steel flow is impacting onto the (king) spider and the flow is redirected in the end-runners so that it flows finally into the ingot mold or moulds. At least during redirection, turbulent flow will occur. During the whole process till the steel is solidified (15–45 min), the steel composition should furthermore not change in terms of chemical composition and inclusions [8–10]. After solidification of the steel, the disposable refractory hollowware is removed from the steel inside it to recycle the metal.

The steels processed by ingot casting are sensitive to the severe bending stresses occurring at high temperatures during continuous casting. Such steels can be highly alloyed with e.g. chromium, manganese, aluminium, and silicon [6, 8, 11].

Based on the process description, formulations of customer needs on the refractories can be deduced. The need to withstand the high temperatures is not included because this is comprised by the definition of a refractory according to the standard DIN 51060. The refractories have to:

1. withstand the fast temperature change during contact with the hot steel,
2. withstand mechanically the partially turbulent flowing hot steel – the spider even a harsh impact,
3. be (chemically) inert against the steel (to not change its composition), and
4. be easily removed.

To evaluate the importances, it is regarded what happens if the need is not fulfilled. The first two needs would lead to the refractory degradation, possibly even spalling, which would reduce the quality of the steel in terms of the third need. Thus, the first two needs are highly important, here evaluated 5.

The third need is standalone but if not fulfilled would reduce the steel quality, too, and is thus evaluated here with 4. The removability of the refractory does not change the quality of the steel product but just of the process-workers would require more time or the steel inside might be not recyclable because it sticks to the refractory. Its importance is therefore lower, here evaluated 2.

3.2 Technological requirements and interactions

The definition of refractories to withstand temperatures ≥1500 °C according to the standard DIN 51060 in solid state entails other requirements as well. During service, refractories do not only have to tolerate high temperatures but also withstand chemical wear (corrosion), physical/mechanical wear (such as erosion/abrasion) and thermomechanical wear (such as thermal shock) which may interact synergistically and superimpose each other.

Other technological requirements are often either thermal insulating or conducting properties and even electrical properties possibly have to be adjusted [12–17]. Besides these technological factors or requirements, ecological criteria are more and more important [18–20].

It can be noted, that for refractories the mechanical strength is not treated as a technological requirement in the literature [21] but rather as a component characteristic influencing e.g. the erosion and thermal shock resistance strongly. This applies also for the physical properties.

All the attacking wear mechanisms contribute to an overall wear rate. The range of exposure conditions in the various applications differs strongly. Usually one wear process is dominant [22]. Thus, it is necessary to select and design the most appropriate refractory for each application [14] but beforehand the dominant wear process has to be identified, which can be done by the House of Quality method.

From the process description in the prior subsection can be concluded that the important technological requirements for refractories for application in steel ingot casting are a thermal shock resistance against a single but severe thermal shock, erosion resistance, mechanical impact resistance, and corrosion resistance [9, 10, 23]. The removability (cf. prior subsection) is coupled to the thermal shock resistance in terms of the remaining strength after the thermal shock [24].

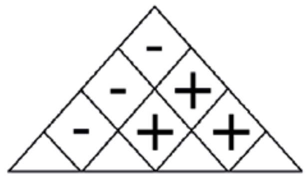
Furthermore, it should be added that the thermal shock resistance comprises the resistance against crack initiation and crack propagation [16, 25]. Their differences are however strongly coupled to the microstructure and are not necessary to be regarded in the planning matrix. Nevertheless, for refractories mainly the resistance against crack propagation is important which is important to know for the interactions between the technological requirements [16, 25, 26].

A simple review of the interactions without regarding the microstructural causes gave the following results:

- The thermal shock resistance may be lower if corrosion and erosion resistance are higher [22].
- Erosion and impact resistances correlate positively [15].
- Erosion and corrosion resistances correlate positively [12, 22].

Consequently, it seems apparent that the thermal shock resistance and mechanical impact resistance also are related negatively and that corrosion and impact resistances are related positively.

Tab. 1 House of Quality (planning matrix) for refractories for application in steel ingot casting (roof: positive interaction "+", negative interaction "–")



Relations
9 – strong
3 – medium
1 – weak

Customer needs	Importance (1 – low/5 – high)	Thermal shock resistance	Erosion resistance	Mech. impact resistance	Corrosion resistance
Withstand temperature change	5	9			
Withstand turbulent flow & impact	5	3	9	9	3
Chem. inertness	4	3	3	3	9
Removability	2	9	3	3	9
Weights		**85**	58	58	69
Practicability (1 – bad/5 – good)		2	2	2	4
Weights · Practicability		170	116	116	**276**

3.3. Preparation of the House of Quality

From the prior subsections, the customer needs (step 1) and technological requirements (step 2) can be directly constructed (cf. Tab. 1). In the next step (step 3), the relationships between the customer needs and technological requirements are evaluated. The technological requirement characterising the ability to withstand a steep temperature change is the thermal shock resistance. Their relation is here thus evaluated 9. The need to withstand turbulent flow and impact is related to the erosion and impact resistances (each strong, here evaluated 9) but also to the corrosion resistance because corrosion can lead to rapid erosion. As the corrosion's influence occurs only indirectly due to the interaction with the erosion resistance, it is here evaluated 3. Furthermore, these resistances are all related negatively to the thermal shock resistance. But it is especially important that the refractory can withstand the erosion and corrosion after the severe thermal shock, which is why the thermal shock resistance is also subjectively evaluated 3 due to its indirect influence. The chemical inertness is logically strongly related (9) to the corrosion resistance. Nevertheless, inclusions can be also introduced due to mechanical spalling or erosion which gives for the other three resistances each a medium relation due to the indirect nature. For the removability, the steel should not stick to the refractory and the refractories strength after thermal shock should be sufficiently low. Increasing roughness due to erosion, corrosion and impact as well as cracks due to thermal shock influence the sticking capability. The thermal shock resistance manipulates, however, in addition the final strength as well as the corrosion resistance is more important because it might not only increase the roughness but detrimental chemical compounds could form between steel and refractory. Thus, these both are strongly related 9 to the removability whereas the other two have only a medium relation 3. With the filled out relationship matrix, then the weights (weighted importance) can be calculated (cf. Tab. 1).

Regarding the practicability, all properties are influenced by the bulk properties like porosity and microstructure like cracks. However, especially the corrosion resistance can also be strongly impacted by the material choice [16] which is much easier to change and has thus a higher practicability. The subjectively evaluated practicabilities and resulting products with the weights are shown in Tab. 1.

4 Conclusions

In the present study, a House of Quality method was successfully applied to link customer needs with technological requirements in a planning matrix on the example of refractories for application in steel ingot casting.

- The method proved to be suitable to identify the technological requirement most crucial to optimise by the weighted importances. In this example this was the thermal shock resistance.
- However, the method revealed also that good results can be obtained very fast by firstly addressing the topic of the corrosion resistance by means of the material selection. This was identifiable by the practicability connected to the weighted importances.

The next step in the chain of what-how linkages is to connect the technological requirements to the component characteristics of refractory materials in a design matrix.

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