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Applying and Producing Indexable End Mills: A Comparative Market Study in Context of Resource Efficiency

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Abstract

In manufacturing processes, aspects like applied tools and milling strategies significantly determine milling operation results and their resource efficiency. Due to the widespread application of Indexable End Mills in high-volume machining processes, considering the impact of these tools on resource efficiency becomes increasingly important.

This paper presents novel insights into different aspects of Indexable End Mills (e.g. produced geometries, applied technologies, operation purposes and machined materials), derived from a study with enterprises applying or producing these tools. The results are discussed in order to identify future research needs to improve resource efficiency in manufacturing enterprises. One of the main results is that 84 % of the surveyed manufacturers and 65 % of the surveyed users of Indexable End Mills evaluate the application of vibration-damped tools as a considerable need for improvement.

Keywords: Indexable End Mill; milling; study

1. Introduction

Due to their high share of value creation in manufacturing, the influence of machining processes and the therein applied cutting tools on profitability and sustainability is often high. Considering that a significant proportion of employees in the European Union earn their salary directly or indirectly from machining products, this key production technology deserves special attention in terms of sustainability [1]. Within machining processes, the applied cutting tools have a significant impact on the economic and ecologic efficiency. This results from the fact that the cutting tool is the most important link between the shear zone in the cutting process and the machine tool itself. As a result of the high thermal and mechanical load of the cutting edge, the machine tool can only provide as much productivity and efficiency as the cutting tool permits [2]. Due to the widespread application of Indexable End Mills in high-volume machining processes [3], a high potential for optimization can be assumed. The study focuses both on tool

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manufacturers and industrial users of Indexable End Mills and thus might contribute to answer urgent questions regarding current trends and developments in the field of machining processes. The results are discussed in order to identify future research and development needs for improving the resource efficiency in manufacturing enterprises which are applying Indexable End Mills.

2. State of the Art

2.1. Indexable End Mills

End mills are preferably used for the milling of grooves, pockets, slots and recesses of all types and sizes as well as for molding surfaces. The high variety of sizes regarding the diameter as well as the almost infinite possibilities to impart new shapes to metal make these tools so multipurpose [4]. These tools can be designed as solid tools or indexable insert tools, cf. Fig. 1 a). [5] These so called Indexable End Mills can be equipped with different inserts, so that, for example, the surface quality can be influenced [6].

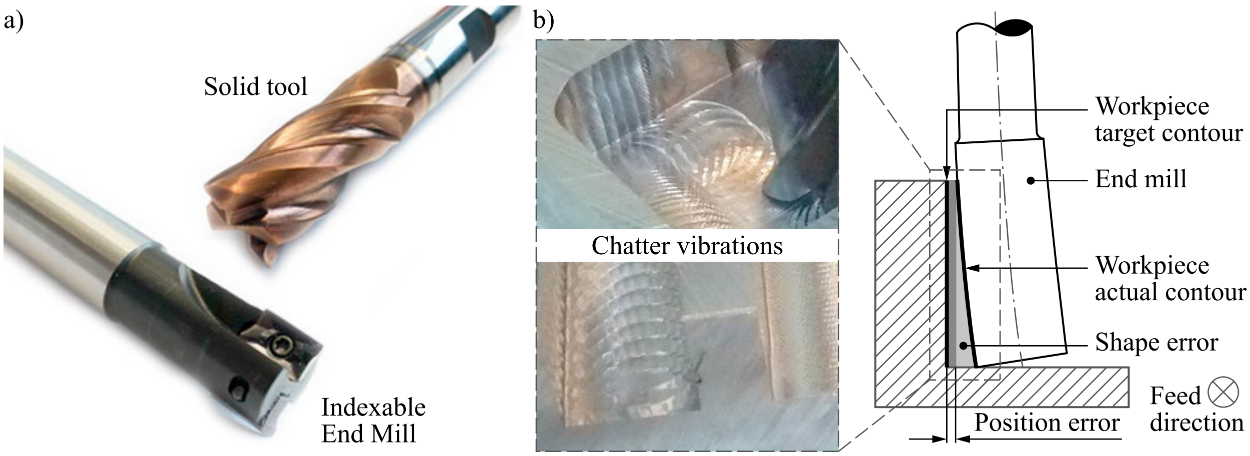

Fig. 1. a) Figure of a Solid End Mill and an Indexable End Mill, b) Bending of an end mill during machining process, following [7], and the results of chatter vibrations

These tools are characterized by their long, slim shape with a length to diameter ratio l/D between 5 and 10, adapted to their respective field of application. Due to the slim shape the process forces occurring during milling push the end mill off and bend it elastically, cf. Fig. 1 b). [5, 7, 8] Chatter vibrations as well as the tool elasticity lead to dimensional and shape errors and thus bar they way to a geometrically ideal profile of the part to produce [9, 10]. These dimensional and shape errors can be corrected by reworking. However, reworking takes extra effort and leads to lower resource efficiency and hence also to lower sustainability of the enterprise compared to the situation that no rework is necessary subsequently to a machining process. Moreover, less vibration leads to reduced tool wear and therefore, to a longer life cycle of the tool which may foster the resource efficiency. However, Indexable End Mills offer the advantages listed below. [8]

- Flexibility in cutting material selection
- Flexibility in the design of macrogeometry
- Optimization of the microgeometry
- High level of utilization
- Large degrees of freedom in cutting tool design

Indexable End Mills focused in this paper are manufactured in diameters ranging from 11 to 40 mm and used for the simultaneous production of two plane surfaces which are arranged right angled to each other. For diameters above 40 mm shoulder cutters are designed as Arbor-mounted Milling Cutters.

During engagement, the indexable insert works on both the face and the circumference. Depending on the design the Indexable End Mills can be equipped with one or more indexable inserts with geometry and cutting material matched to the respective machining task. The mount of the indexable insert in the seat is carried out for medium loads with one screw. Due to the large space requirement of this type of mount, a wide division is necessary. Common shafts, also with internal cooling, are possible as an interface to the chuck. [8]

2.2. Study

In order to discover new insights and collect purposeful data properly scientifically based research methods and a planned research process are required. These two aspects can be taken into account by focusing on an ideal market research process. [11] For this purpose, different types of process models which are essentially similar are described in literature. Depending on how many individual steps are summarized in a process phase, these process models are divided into five [12], seven [13] or ten phases [11]. The sequence of a study in a five-stage process model according to Magerhans is shown in Fig. 2 [12]. This sequence is based on the seven-stage process model according to Kuss [13] while partly aspects of Homburg are introduced [11].

❶ Definition ⟶ ❷ Design ⟶ ❸ Data collection ⟶ ❹ Data analysis ⟶ ❺ Documentation

Fig. 2. Five-phase model of the market study, according to [12]

In the definition phase the object of investigation and the research objectives are defined. In the design phase, the examination design is determined, and the survey is designed. In the data collection phase, suitable addressees are selected, and the scope of the survey is determined. In the data analysis phase, the collected data is evaluated. The documentation phase includes the summary of the results, suggestions for further market research activities and recommendations for future research and development.

3. Approach and Study Design

A standardized survey was developed and sent to a variety of enterprises by email. The collected data has been analyzed and summarized. Subsequently, a comparative analysis of different groups of participants has been carried out.

The surveys consists of two different aspects. One aspect is the description of the status quo, the other aspect the identification of potentials for development. These two aspects require different question designs. The description of the status quo is descriptive and uses quantitative methods that provide numerically measurable and comparable results. The determination of potential for development has an explorative character and is conducted with qualitative methods. The implementation of these two research approaches is carried out within the framework of a standardized survey by using different question formats. A distinction is made between closed and open questions. Additionally, there are hybrid forms between these two formats. Closed questions serve to collect quantitative results, whereas open questions are apt to gain new insights in the course of qualitative research.

The survey is divided into a total of six topics, as shown in Fig. 3.

❶ Industry affiliation	⟶	❷ Machining processes	⟶	❸ Milling tools	⟶	❹ End mills	⟶	❺ Indexable End Mills	⟶	❻ Enterprise
# 2 (n)		*# 2 (m)* *# 4 (u)*		*# 1 (m)* *# 4 (u)*		*# 3 (m)* *# 3 (u)*		*# 7 (m)* *# 10 (u)*		*# 6 (n)*

 # number of questions; (n) nonspecific; (m) manufacturers; (u) users; ⟶ *sequence of questions*

Fig. 3. Study design

The survey is directed to both manufacturers and users of Indexable End Mills. In order to be able to display the relevant questions for these two groups, the interviewees must choose which of these groups they belong to. [14]

In general, three types of questions depending on the type of participant exists: first, non-specific issues that are relevant to all participants, second, manufacturer-specific questions that only concern the manufacturers of Indexable End Mills, and thirdly, user-specific questions that are relevant only to users of Indexable End Mills.

Research at associations, Chamber of Crafts and the like identified 59 enterprises in Germany as possible manufactures of Indexable End Mills. In the course of further research and contact with the enterprises, it turned out that 28 enterprises are suitable as participants for the survey, see Fig. 4 a). Of these 28 candidates, 20 completed the survey, which corresponds to a response rate of 71 %, cf. 4 b).

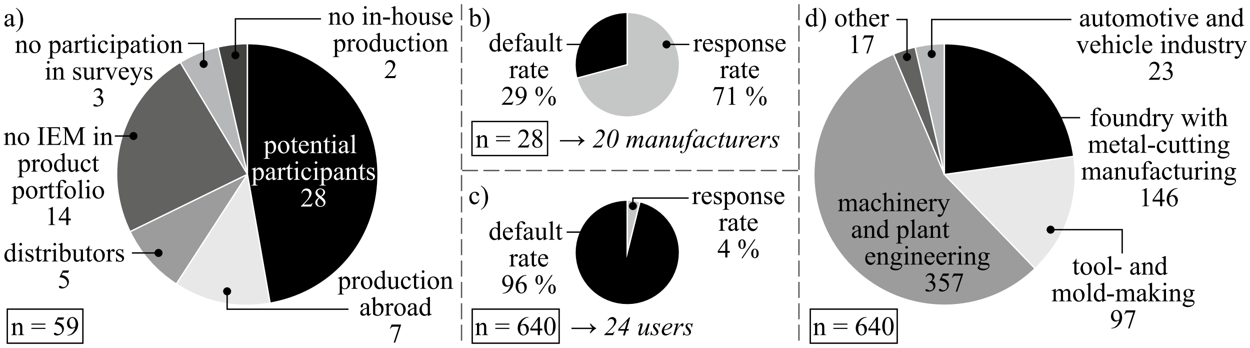

Fig. 4. a) Sample size of manufacturers of Indexable End Mills, b) Response rate of manufacturers of Indexable End Mills, c) Sample size of users of Indexable End Mills d) Industries and scope of users of Indexable End Mills

As possible users of Indexable End Mills, a total of 640 enterprises from different industries were contacted, see Fig. 4 d). Of the enterprises contacted, a total of 24 surveys were completed, which corresponds to a response rate of 4 %, cf. Fig. 4 c). The significantly lower response rate may have several reasons. It is difficult to predict if a company is using Indexable End Mills. Moreover, users of Indexable End Mills benefit less than the manufacturers of Indexable End Mills from the study's findings and therefore have less motivation to participate in the survey.

4. Results and Discussion

In this section, the results of the study are presented and discussed. First of all, the surveyed enterprises are described in terms of different characteristics, like the size of the company. Then, the manufacturers and users of Indexable End Mills are compared to each other concerning their respective evaluation of the relevance of general target dimensions in machining as well as of needs for improvement related to Indexable End Mills. Subsequently, major requirements and barriers of the application of vibration-damped Indexable End Mills are indicated independently on company characteristics. Finally, more detailed results based on preceding findings are presented.

4.1. Surveyed enterprises

To get first insights into the structure of the enterprises that responded to the study, both manufacturers and users of Indexable End Mills were asked about their number of employees. Then, the enterprises have been categorized according to the EU recommendation 2003/361 [15]. As shown in Fig. 5 a), more than half (55 %) of the surveyed manufacturers of Indexable End Mills represent small and medium-sized enterprises whereas 40 % represent large enterprises. Moreover, five % of the surveyed manufacturers of Indexable End Mills could not be evaluated regarding their size since they have not provided the necessary data.

The distribution of the size of surveyed users of Indexable End Mills is shown in Fig. 5 b). Small and medium-sized enterprises have the same share as large enterprises (46 % each) whereas 8 % of the surveyed users of Indexable End Mills could not be evaluated regarding their size due to missing data.

The distribution by the industry sector of the surveyed enterprises that are using Indexable End Mills, is shown in Fig. 5 c). The machinery and plant engineering sector is the most mentioned industry sector with a share of 50 % followed by the tool- and mold-making sector, which has a share of 36 %. Other industry sectors have a total share of 14 % and include the automotive industry, the contract manufacturing industry and the optical goods industry.

Furthermore, the surveyed users where asked about the materials being machined by Indexable End Mills. In Fig. 6 the results are shown in decreasing frequency. The most commonly mentioned materials are different types of steel and aluminum.

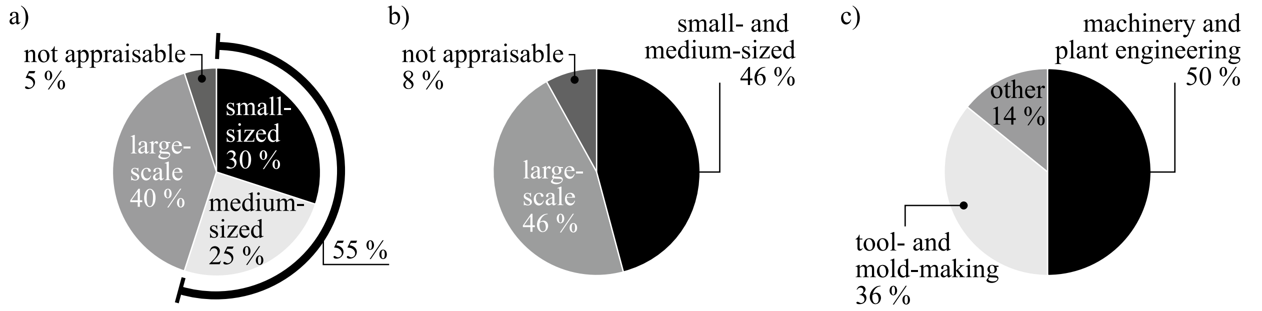

Fig. 5. Structure of the surveyed enterprises based on size (a) manufacturers and b) users) and industry sectors of the users (c))

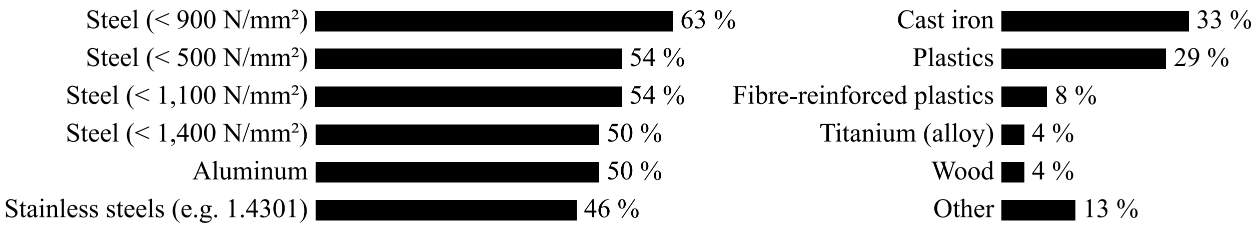

Fig. 6. Distribution of materials machined by Indexable End Mills

Another question dealt with user behavior of Indexable End Mills, see Fig. 7. The majority (71 %) of the surveyed users apply Indexable End Mills with a diameter between 11 and 20 mm and 42 % with a diameter between 21 and 40 mm. 21 % of the surveyed users also apply Indexable End Mills with a diameter larger than 40 mm. In addition, the surveyed users were asked about the applied length to diameter ratio l/D. The most common application was a length to diameter ratio smaller than 5 in the considered tool diameter ranges. A length to diameter ratio greater than 10 only be found in Indexable End Mills with a diameter greater than 40 mm. The last question in this context dealt with the number of cutting edges. Only for diameters between 11 and 20 mm two cutting edges are used. For diameters ranging from 11 to 20 mm and 21 to 40 mm four cutting edges are used most frequently. For diameters larger than 40 mm more than five cutting edges are usually used.

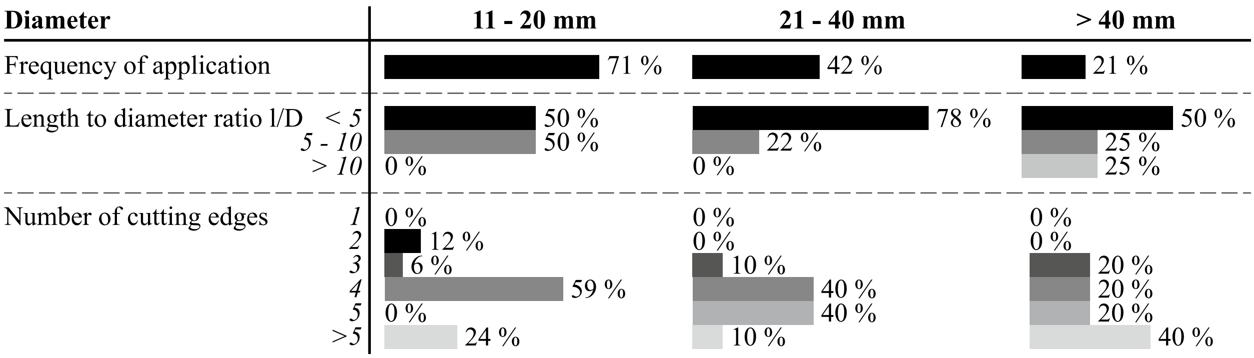

Fig. 7. Current use of Indexable End Mills

4.2. Comparison of manufacturers and users of Indexable End Mills

To provide an overview of the relevance of general target dimensions, manufacturers of indexable end mills were asked to evaluate the relevance of predefined general target dimensions at their customers when it comes to the optimization of the machining processes. Besides, users of Indexable End Mills were asked to evaluate the relevance of predefined general target dimensions from their perspective when it comes to the optimization of the machining processes. The results of these questions are shown in Fig. 8 subdivided into the answers of the surveyed manufacturers and the answers of surveyed users. It can easily be seen that the differences between manufacturers and users are quite low. According to the survey, quality represents the highest rated predefined target dimension followed by processing time whereas energy consumption is rated as most unimportant among the predefined target dimension.

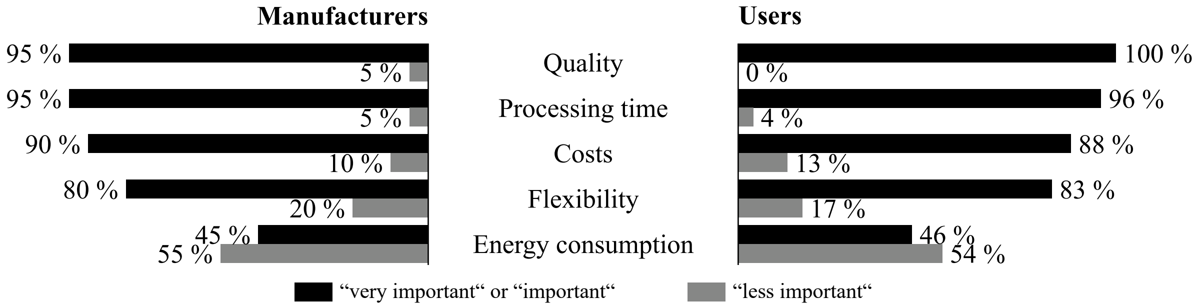

Fig. 8. Target dimensions of machining processes

Much higher differences between the surveyed manufacturers and surveyed users of Indexable End Mills occur within the evaluation of the needs for improvement. Manufacturers of Indexable End Mills were asked to evaluate the relevance of predefined needs for improvement at their customers whereas users of these tools were asked to evaluate the relevance of predefined needs for improvement of Indexable End Mills from their perspective. Fig. 9 shows that both the manufacturers and the users of Indexable End Mills evaluate vibration-damped tools as a considerable need for improvement.

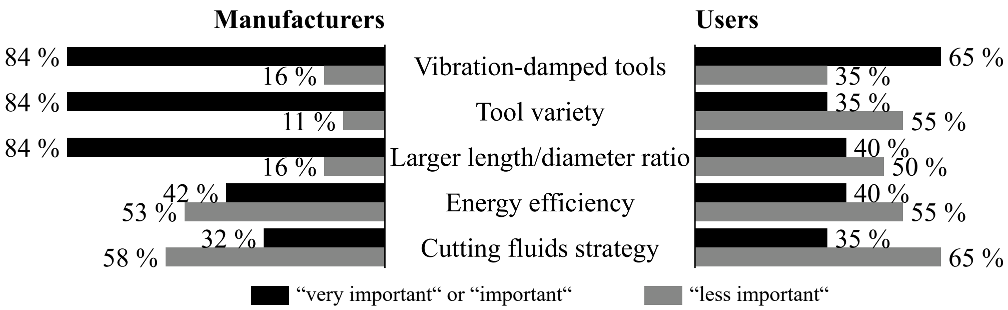

Fig. 9. Need for improvement of Indexable End Mills

4.3. Significant room for improvement – vibration damping of Indexable End Mills

The application of vibration-damped Indexable End Mills seems to be a promising improvement potential. To provide deeper knowledge about this application, users of Indexable End Mills were asked to indicate specifically their conditions that have to be fulfilled prior to this application. The results of this question are shown in Fig. 10. Three-quarter of the surveyed users stated that they would apply vibration-damped Indexable End Mills only on the condition that no additional devices are necessary. Furthermore, more than half (58 %) of the surveyed users stated the deployment of the same tool clamping as deployed for other tools as a condition to be fulfilled.

Regarding the barriers to use vibration-damped Indexable End Mills, 75 % of the surveyed users of Indexable End Mills stated a disadvantageous cost-benefit ratio. Another 13 % stated that they are bound by framework contracts. Other barriers play only a minor role (see Fig. 10).

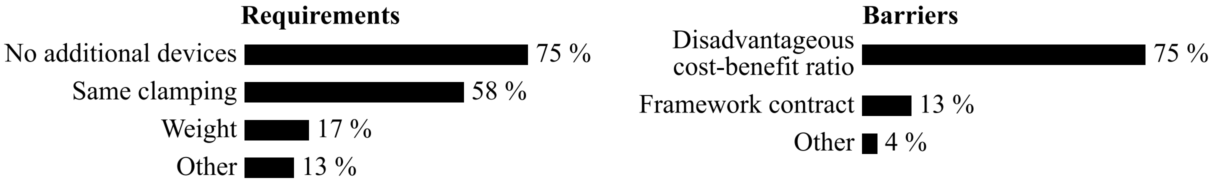

Fig. 10. Requirements and barriers to use vibration-damped Indexable End Mills

4.4. *User requirements for vibration-damped Indexable End Mills*

In the following, study results addressing the application of vibration-damped Indexable End Mills are presented in dependence on different enterprise characteristics. First of all, the need for optimization of the vibration-damping of Indexable End Mills is stated by 70 % of the surveyed enterprises of the tool- and mold-making sector and by 73 % of the surveyed enterprises of the machinery and plant engineering sector as strong or even very strong. The results are shown in Fig. 11.

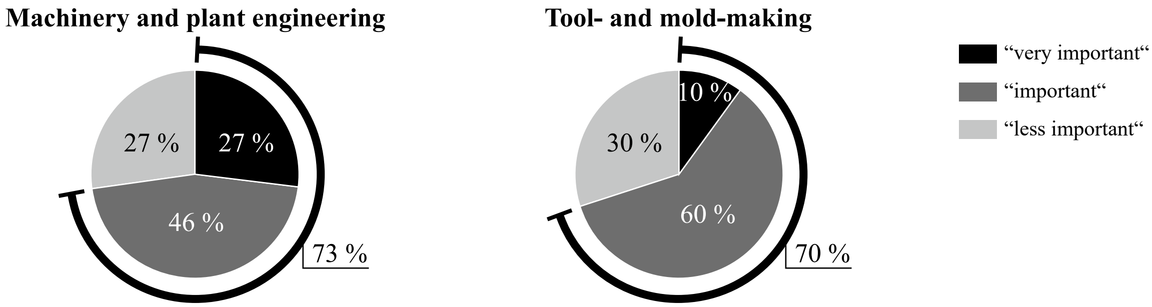

Fig. 11. Application of vibration-damped Indexable End Mills in dependence on different enterprise characteristics

Subdivided into the size of responding enterprises, 50 % of large enterprises and 78 % of small and medium-sized enterprises consider the need for optimization of the vibration-damping of Indexable End Mills as strong or even very strong, see Fig. 12 a).

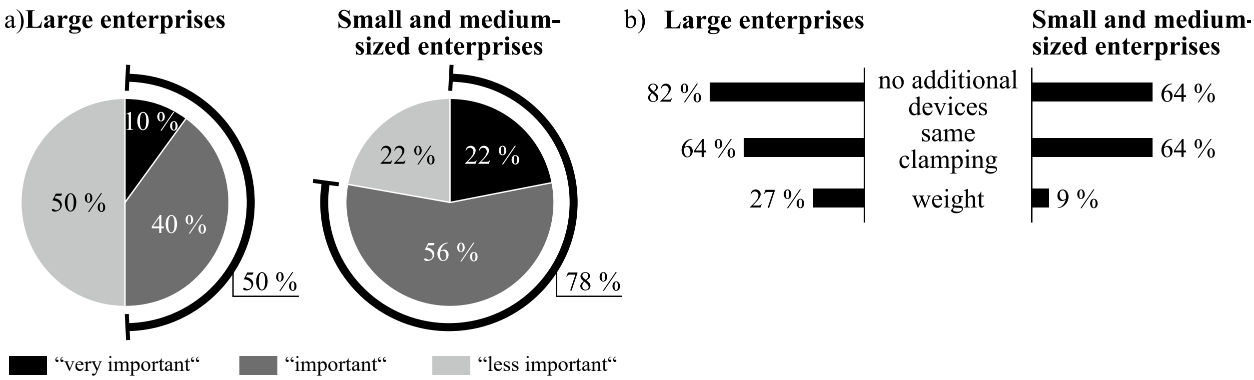

Fig. 12. Application of vibration-damped Indexable End Mills in dependence on different size of enterprises

Lastly, among the enterprises that responded to the study, 82 % of large enterprises and 64 % of small and medium-sized enterprises stated that they would apply vibration-damped Indexable End Mills only on the condition that no additional devices are necessary, see Fig. 12 b). Furthermore, 64 % of large enterprises and 64 % of small and medium-sized enterprises stated the deployment of the same tool clamping as for other tools as a condition to be fulfilled. In addition, 27 % of large enterprises and 9 % of small and medium-sized enterprises stated that light weight is critical to their use.

5. Conclusion and Outlook

The survey addressed both manufacturers and users of Indexable End Mills. In addition to general information on size and industry sector, information about specific issues were collected. These indicated, for example, that quality and process time are much more important than energy savings. At first, this may seem to contradict the aim of resource efficiency, but studies show that reducing the process time provides a higher potential for increasing energy efficiency compared to reducing the process load [16, 17]. The study showed that 84 % of manufacturers and 65 % of users identified vibration-damping as the most promising need for improvement of Indexable End Mills. The surveyed users stated that the conditions that no additional devices are needed and the same clamping can be used are compulsory for the acceptance of new vibration-damped tools whereas a disadvantageous cost-benefit ratio is regarded as a main barrier. In addition, research was conducted on the user behavior of Indexable End Mills between machinery and plant engineering and tool- and mold-making, as 86 % of the surveyed enterprises belong to these industry sectors. These results can be used by manufacturers of Indexable End Mills as a base for future tool developments to facilitate an achievement of customer requirements. This fosters the competitiveness and in turn a sustainable success of an enterprise.

Especially the upcoming digital transformation of traditional industrial markets will affect machining processes and the applied cutting tools in a considerable way. In this context, a clear conflict of goals between steadily increasing productivity with high resource efficiency, broad product variability and high process complexity, new materials, cutting tools and software – as well as recent legal and environmental-protection requirements – can be identified. Therefore, in the future, it should be a question of developing strategies and solutions with which the previously mentioned conflicts and challenges of the digital transformation can be systematically and quickly counteracted. To ensure competitive and sustainable machining processes in the future, a comprehensive knowledge regarding Indexible End Mills is indispensable and can only be achieved by the collaboration of industrial engineering experts, material scientists, metal cutting researchers and computer scientists. Particularly in tool management and smart tool approaches, the holistic co-operation between users and machine tool manufacturers, cutting tool manufacturers, consulting experts as well as IT-enterprises is promising.

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