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SELECTION OF MANUFACTURING CONCEPTS FOR SMALL BATCH SHEET METAL FORMING OPERATIONS

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ABSTRACT

Manufacturing process design for small batch sheet metal forming operations demands special concepts like incremental forming, forming at locally increased temperatures, rapid tooling, fast and reliable preparatory operations,... According to this it is needed to improve and control friction conditions and to combine mentioned concepts for optimal technological solutions.
The objective of the proposed work is to study specific production parameters for particular manufacturing process considering also their integration into uniform system. For this purpose the decision making matrix shall be determined focused on the optimal selection and combination of available technologies for the small batch. The set-up of such decision matrix linking conventional and new innovative forming processes and at the same time assuring their robustness in all steps is new in the sheet metal forming of small batch components.
Keywords: *Small batch production, Sheet metal, Technology selection*

1. INTRODUCTION

The developing countries with limited human and material resources should be very careful at selecting their strategic orientations. One of the crucial long term strategies could be to change the status of supplier to partner for automotive industry but this connection could only be retained with continuous improvements of production technologies and development strategies. The paper presents the linkage of modern forming technologies and concepts into one system enabling fast and reliable activities in the development phase of new products and their preparation for the real testing procedures. Parameters of all implemented technologies have to be well determined and analyzed into the detail prior to the determination of a decision-making system. Once the technological parameters and limitations of each manufacturing concept and/or technology are determined the set-up of decision-making matrix will enable the selection of optimal technological combinations for particular sheet metal part. The set-up of such decision matrix is in the field of sheet metal fabrication new and innovative approach for the manufacturing of the small batch components.

2. SMALL BATCH PRODUCTION TECHNOLOGIES

The authors have analysed the state-of-the-art of small batch production already in some research projects where it was found out that there are several concepts and technologies for such production volumes. However, these technologies are mostly not linked together and there are rare combinations of various manufacturing technologies for fast prototyping and small batch series production. Therefore, the idea of linkage various fast prototyping and small batch production represents innovative approach to integral search of optimal combinations of manufacturing technologies. To assure efficient linkage of various technologies and concepts a decision-making matrix should be establish by incorporating specific characteristic of particular manufacturing technologies. The matrix supports fast and efficient selection of manufacturing technologies which meet the specific predefined boundary conditions of each individual analysed product. According to the needs in the automotive sector it was pointed out that the decision-making matrix should incorporate parameters of following four topics – figure 1:

- Incremental forming,
- Forming with conventional fast manufactured tool,
- Friction conditions at forming,
- Warm forming.

Each of the thematic topics will be separately analysed to assure the quality and reliable input parameter data for the decision-making matrix.

2.1 Incremental forming

Incremental sheet metal forming represents modern process for prototyping and small batch series production. The process itself is relatively slow and in comparison to conventional forming processes like deep drawing of stretching. The main advantage of the incremental forming is its nature to omit expensive forming tools for the part production. In contrariety to complex forming tools for conventional forming processes the incremental forming needs only simple support tool and rod-shaped tool used to form the sheet metal. The concept of incremental forming itself is known already for a longer period but its application as a modern innovative approach for the small batch series production is in use for about ten years. The processes of the incremental forming can be divided according to the forming tool movement or movements of two tools and the type of the used support (figure 2) to:

- Incremental forming of the sheet metal with specific support tool (ST),
- Incremental forming of the sheet metal with a general ST,
- Incremental forming of the sheet metal without ST (single point incremental forming - SPIF),
- Incremental forming of the sheet metal with a moving ST.

In previous studies of incremental forming processes the key parameters have been determined [2]. It was pointed out that the forming force can be selected as one of the crucial process parameters [3]. The forming force changes significant and rapidly with changes of other process parameters as well with undesired events in the manufacturing process. The forming force is influenced by the intensity of the thinning as well by the intensity of the material hardening. Generally three different forming force trends can be observed which can be illustrated with the variation of the inclination angle α as presented on figure 3. In case of limit inclination angle (α=75°) the force increases rapidly due to fast hardening of the material following by the typical drop of the forming force at the start of the intensified thinning. This thinning is followed by the localisation and finally the rupture of the workpiece.

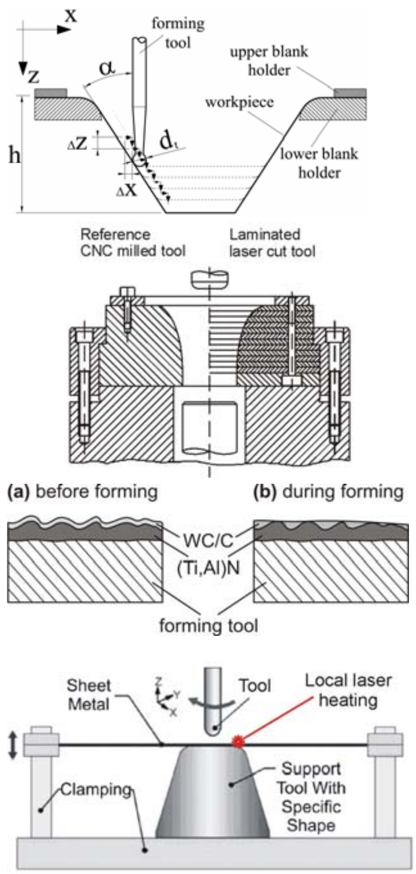
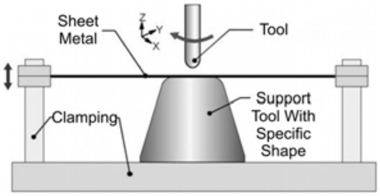
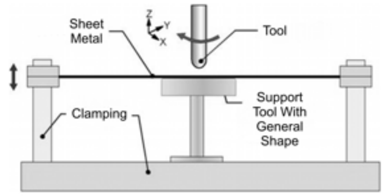


Figure 1 - Analysed topics of decision-making matrix

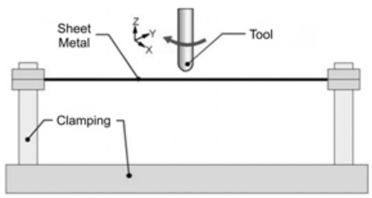
However, the drop of the forming force at incremental forming can be assumed as a critical indicator when the material's rupture is analysed and the accurate analysis of the force distribution during the forming cycles is indispensable. Previous research work has shown also that limit inclination angle α is an important parameter of the process suitability for particular part production. Therefore, the inclination angle represents one of the rare process limitations of incremental forming process [3] which has to be considered during the development phase of a new product. The inclination angles are dependant of interactions between the rod-shaped forming tool and the sheet metal but the major influence has the properties of the formed material, its formability and thickness.



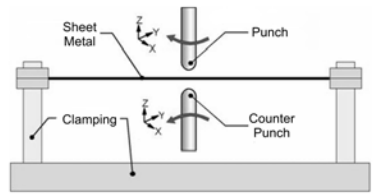
IF with support tool



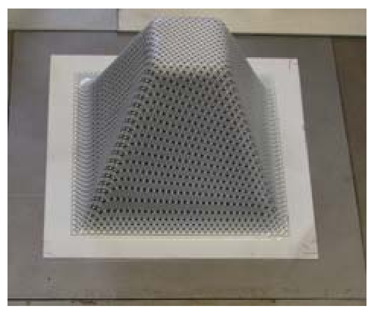
IF with general support tool



IF without support tool



IF with a moving support tool



Test workpiece manufactured without support tool.

Figure 2 - Types of the incremental forming processes (according to [1]) and the test workpiece

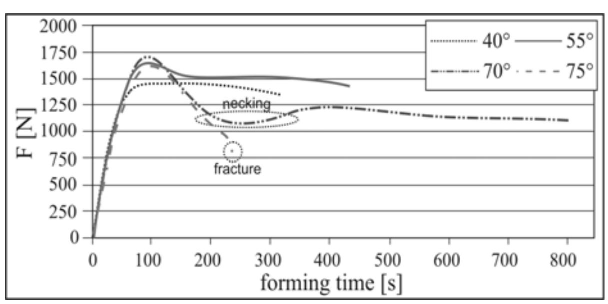


Figure 3 - Different force trends in case of steel DC05 - 1 mm in thickness

If thicker sheet metal is applied higher inclination angle can be achieved. A lot of researches were made in order to investigate formability of differently thick sheets varying from 0.23 to 5 mm [3, 4, 5, 6, 7]. The investigation made by Petek et al. [6] showed that an interesting alternative is to substitute the rigid forming tool with a high velocity water jet especially when thin sheets are used. A major difference between rigid tool single point incremental forming (RTSPIF) and water jet incremental forming (WJSPIF) is in the process controlling principle. In RTSPIF the main process parameter is the tool kinematics, which defines the loads acting on the workpiece, whereas at WJSPIF the main process parameter is the water pressure, which defines the loads on the workpiece. The results of the investigation show that different forming mechanism influences the size of inclination angle [6].
Beside all other influential parameters different workpiece shapes have also great influence on the wall inclination angle, since each of the standard product shapes presents unique deformation states. The results from the investigations [3, 6, 8], where various product shapes were formed (figure 4), show that on the extreme concave surfaces (e.i. edge) lower wall angle could be achieved in comparison to flat surfaces.

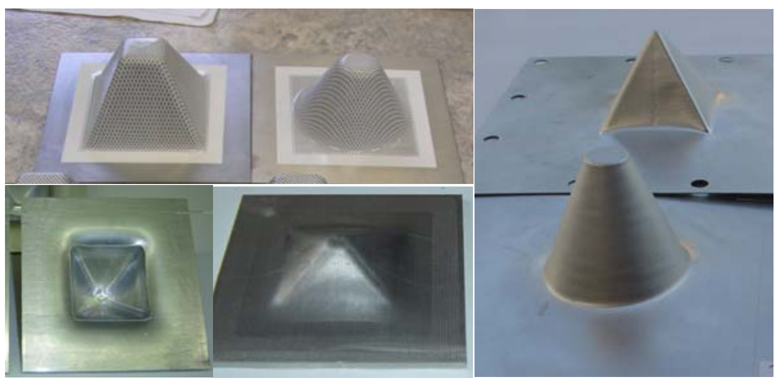


Figure 4 - Analysed product shapes at SPIF [3, 6, 7, 8]

2.2. Fast manufactured conventional tools

Since the incremental forming posses particular technological limitation the research group started to study an idea to combine conventional and incremental forming. Using the conventional sheet metal forming with geometrically simple tools the first deep drawing operation could be performed to assure the necessary material movement. Finishing of the semi-product to its final dimensions with emphasis on fast manufacturing of part details will be done by the incremental forming. The conventional forming tools can be manufactured with various methods ranging from high speed milling to laminated tooling technology [4]. Despite strong developments of high speed cutting technologies the developed concept of layered tooling cut by 3D CNC laser centre is still one of the most promising solution for fast tooling of conventional tools for sheet metal forming [9]. The laser cut lamellas were already successfully combined with thicker layer in order to obtain flexible tooling solutions [9, 10] – figure 5. For optimal technology selection the combination of layered tooling, CNC milling on direct laser sintering of active tool parts can be used [11].

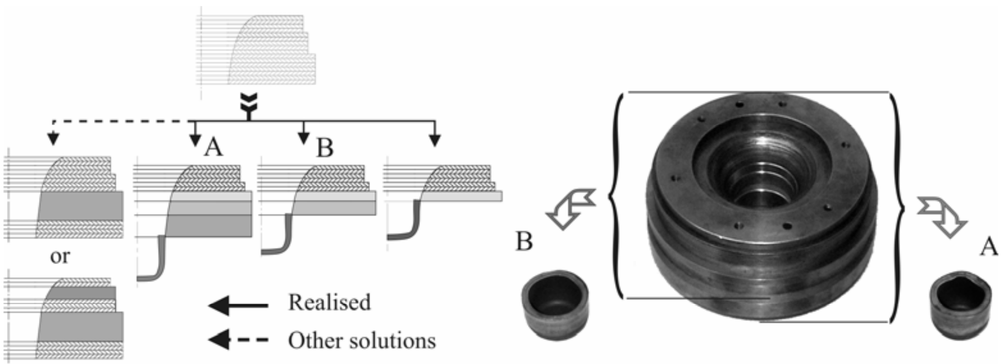


Figure 5 - Combined layered technologies for increased tooling flexibility [9, 10]

2.3 Friction conditions

High pressures at the incremental forming and conventional forming of thick sheet steels are under particular conditions necessary for successful forming but they are clearly undesired in some cases where they affect part surfaces. For better understanding of those problems the use of various lubricants and tool coatings should be studied to assure optimal contact conditions between the tool and workpiece. In the majority of the process operations by the incremental and conventional forming the lubrication of the workpiece and/or active tool parts is necessary. Additionally to this it is necessary to respect minimal environment burdening [4, 5].

To assure optimal friction conditions and decrease the amount of environmental unfriendly lubricants the coatings on the basis of hard carbon (e.g. diamond like carbon - DLC) on forming tools for incremental forming were studied [5, 12]. The DLC coating was compared with the commonly used hard coating CrN and combination of TiAlN + DLC coating. Figure 6 shows the influence of hard coatings on the friction coefficient at SPIF.

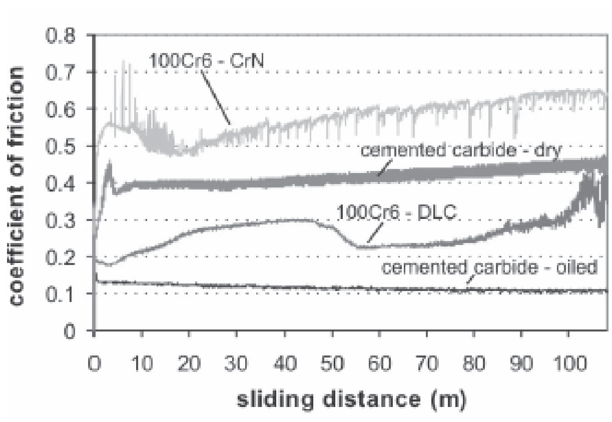


Figure 6 - Friction coefficients as a function of materials in contact [5]

2.4 Warm forming

Materials for the sheet metal industry are exceeded the range of various steel grades despite steelmakers efforts to improve the materials' quality with new grades and surface coatings. Therefore the research work should be focused towards the implementation of several new materials from numerous steel grades and thicknesses as well as light alloys and titanium alloys. In particular the forming of some light alloys is critical due to the relatively low formability. To overcome the problems of magnesium forming the warming of the entire blank or local heating is commonly used. This heating concept of formability improvements by magnesium alloys is more appropriate for the incremental forming. As it is known [13] some incremental forming operations were already performed at elevated temperatures where the workpiece was locally heated by a laser beam.

3. DECISION -MAKING SYSTEM

The optimal selection of adaptable technology needs in the first phase the comprehensive decision-making matrix which consists technological parameters of all studied technologies and their limitations, crucial parameters and selection rules to find optimal technology or combination of technologies for fastest and cost-effective part production.
Determination of optimal concepts and technologies for robust small batch production from conventional and advanced sheet metals (like steel composites) demands knowledge of exact interactions between particular implemented technologies and manufacturing concepts. Accurate analysis of the state-of-the-art, preliminary knowledge of potential users of the decision-making system is crucial for the latter realisation. It is necessary to define all influencing parameters from the material characteristics, specific parameters of each technology and manufacturing concept, heat generation by the process and/or external additional heating affecting the friction between the tool and the workpiece.
Each manufacturing concept and selection of its material-technological-tribological parameters should be connected to the knowledge database where material and technological data are obtained experimentally (figure 7) or by numerical simulations.

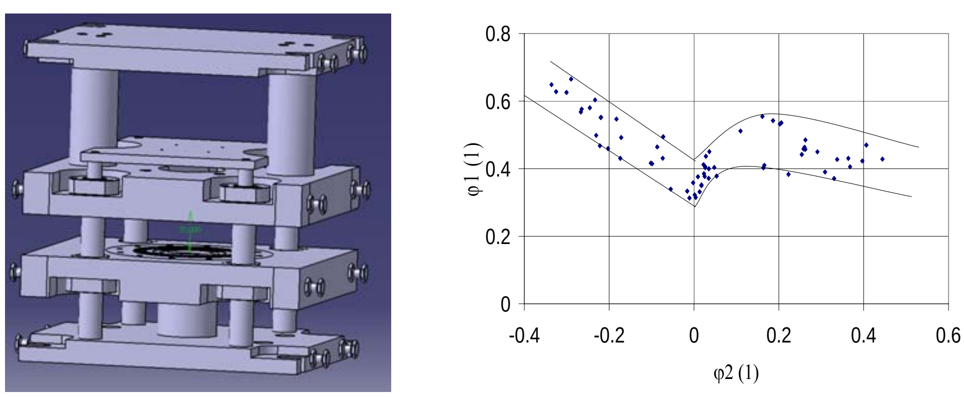


Figure 7 - System for determination of forming limit diagram [14]

The system will contain the technological feature base as well as the material data base and user interface. In the nearest future the system will be extended by cost models and rules for determining production times.
After defining material, technological and economical parameters related to the batch size for a particular sheet metal part the logical linkages among individual topics will be established. In this linkage the topics »Warm forming« and »Friction« represent mainly the support for the »Incremental forming« and »Conventional forming« which are on the equivalent level. Both technologies are complement and one objective in the decision making matrix is to analyse the small batch production with combined conventional-incremental forming concept - figure 8.
The decision-making system design is performed parallel to the research work of all four thematic topics. However, it is not possible to determine all parameters of the decision-making matrix and their linkages and relations without data for the thematic topics.

3.1 Decision-making matrix

Some of the linkages and relations of the decision-making matrix have been determined directly after the analysis of the state-of-the-art and according to the own preliminary research work. The majority of the relations and parameters of the decision-making matrix will be added during the set-up of the decision-making system. The open structure of the decision-making matrix will offer its expansion according to new gained knowledge, to other prospective modern technologies like i.e. hydroforming [15], concepts and cognitions in the area of the small batch production of sheet metal parts is a precondition for its industrial implementation.

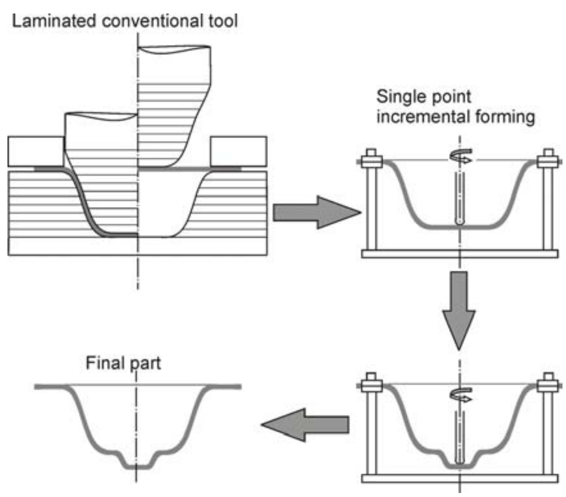


Figure 8 - Combination of conventional and incremental forming

It is to expect that some of technological relations will dependant to the nature of the individual produced parts. Additionally to the general description of technological, design and economical parameters the particular individual parameters and logical connections necessary in individual industrial branch will be implemented as well.
The conceptual set-up of the decision-making matrix is presented on figure 9. Since each manufacturing technology and/or concept offers particular advantages for part production the

decision-matrix has to recommend the selection of the optimal technology according to the determined input parameters as the accuracy, time, allowed thinning, surface roughness etc. are. The presented matrix is in development phase, there are already industrial applications offering the test data for the matrix itself as well as the entire decision-making system.

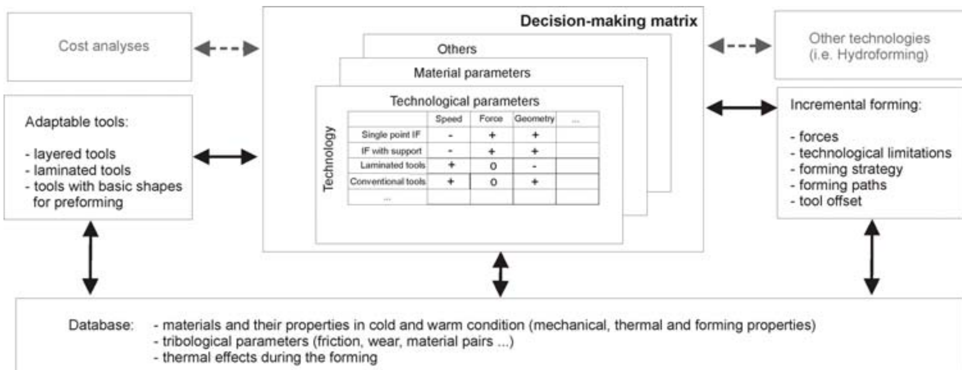


Figure 9 - Decision-making matrix

4. CONCLUSIONS

The adaptable technology selection for prototype and small batch production demands fast response to the changes of various geometrically and technologically different customer needs. In the conventional mass production most of those orders for sheet metal parts demands complex technology selection with several forming steps and expensive tooling which is too expensive for small batch production. Therefore, alternate technology solutions and concepts are needed in order to assure small batch series production fast and for reasonable price. The alternate concepts like incremental forming, forming with layered-structured tools or combinations of both represent cost effective solution for such part production. However, the selection of alternate forming technology or concept has to offer optimal production solution.

The core of presented system is decision-making matrix with linkages to technological, material and other parameters for specific manufacturing technology supported by the database of used materials and tribological conditions. In the future the open technological platform will enable addition of other promising technologies for small batch production of sheet metal components. The development of a computer program for easy-use of the decision-making system is also planned for the near future.

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IZBOR POSTUPAKA ZA IZRADU DELOVA OD LIMA DEFORMISANJEM KOD MALOSERIJSKE PROIZVODNJE

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ABSTRACT

Projektovanje procesa proizvodnje delova od lima deformisanjem u slučaju maloserijske proizvodnje zahteva primenu specijalnih postupaka obrade kao što su inkrementalmo deformisanje, deformisanje sa lokalnim zagrevanjem, kao i postupaka za brzu izradu alata, brzo i pouzdano određivanje pripremnih operacija itd. Da bi se postiglo optimalno tehnološko rešenje neophodno je kombinovati ranije navedene postupke i poboljšati kontrolu trenja i uslove podmazivanja.

Cilj ovoga rada je analiza specifičnih parametara proizvodnje kod pojedinih postupaka izrade delova od lima uzimajući u obzir mogućnost njihove integraciju u jedinstveni system. U tu svrhu biće definisana matrica za odabir odgovarajućeg postupka sa fokusom na optimalan izbor i kombinaciju mogućih postupaka izrade kod maloserijske proizvodnje. Uvođenje jedne takve matrice koja povezuje konvencionalne i nove-inovativne postupke obrade deformisanjem i koja isto vreme osigurava mogućnost njihove pune implementacije u svim fazama je novina u maloserijskoj proizvvodnji delova od lima.

Ključne rečis: *Maloserijska Proizvodnja, Oblikovanje lima, Izbor tehnologije*