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Flexibility in metal forming

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ABSTRACT

Flexibility in metal forming is needed more than ever before due to rapidly changing customer demands. It paves the way for a better control of uncertainties in development and application of metal forming processes. Although flexibility has been pursued from various viewpoints in terms of machines, material, process, working environment and properties, etc., a thorough study of the concept was undertaken in order to with problems of manufacturing competiveness and tackle new challenges of manufacturing surroundings. Therefore, in this paper, flexibility in forming is reviewed from the viewpoints of process, material, manufacturing environment, new process combinations and machine–system–software interactions.

1. Introduction

1.1. Background and motivation

The manufacturing sector undergoes drastic changes in the global scale due to the advent of a new industrial revolution, the so-called fourth industrial revolution or Industry 4.0 [170]. A key feature of this revolution is the increasing interaction of human beings, production machines and products. As a consequence, conventional mass production is changing gradually towards manufacturing systems for mass customization, with higher flexibility and on-demand manufacturing, which brings about new technological challenges. Such a new industrial wave demands connectivity, automation and intelligent systems, in mass customization and on-demand manufacturing in addition to mass production as summarized in Fig. 1 [184].

The mentioned connectivity and intelligentization enable realization of automated manufacturing of products and related automated services. The pursuit of these three factors would finally lead to super-connection and super-intelligentization of human beings, things and space, and ultimately resulting in systemic innovation of industry and society.

While flexibility is inherent to manufacturing processes such as machining and welding, die-based manufacturing processes such as metal forming and casting are increasingly challenged to meet the demands on flexibility.

A working group study on mega-trends and the future of metal forming [127] in 2012 revealed the importance of flexibility. Theresults of the study were summarized as shown in Fig. 2. Various areas, including flexibilitization, intelligent processes, complexity of shape and integration of functions, all of which demand for flexibility of forming either directly or indirectly. 3D printing of metals was included as a separate category, though not having been included in traditional forming, but it becomes a very powerful means of highly flexible manufacturing for producing metallic parts and dies with reasonable productivity for some industrial manufacturing sectors.

Flexibility of metal forming has become an important issue in recent manufacturing demands and plays an essential role in customized mass and individualized production in the manufacturing industry. As flexible sheet metal forming, single point incremental forming has been widely employed and subject to extensive research [61,73]. The introduction of double point (sided) incremental forming had enhanced the formability and extended the range of shape complexity [125,199]. The combination of incremental forming and conventional sheet forming processes further extended the capability of incremental forming

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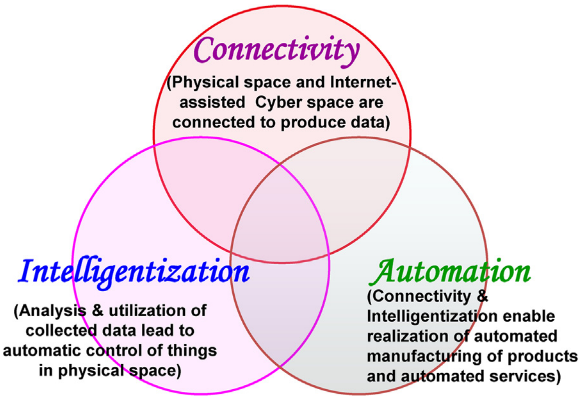

Fig. 1. Three key factors pursued in industry 4.0.

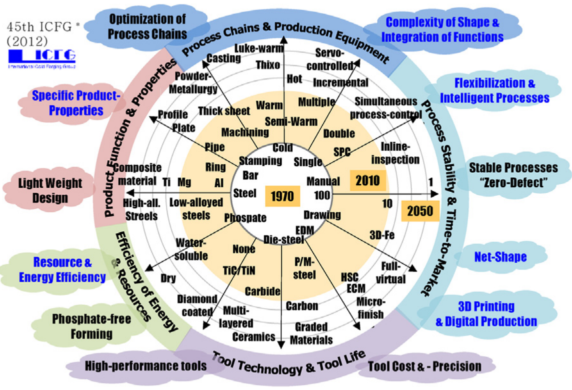

Fig. 2. Mega-trends and future of metal forming [127].

with additional advantages including increased productivity [13]. Incremental bulk metal forming has a long history since the Bronze age. Since then, incremental bulk forming has been developed by employing various forming processes including forging typically and many incremental forming processes using rotating tools such as flow forming, rotary swaging, orbital forming, gear rolling, pierce rolling and ring rolling, etc. [52]. Various flexible forming processes for both sheet and bulk can be found in Japan and they are well summarized in Ref. [8].

Incremental forming is surely the key flexible forming process and has been diversified for manufacturing various metallic products. However, flexibility in forming has been pursued from diverse viewpoints in terms of complexity, material, process, working environment and machine, etc. In this work, flexibility is newly viewed and subjected to review from various angles of perspective in order to provide new prospects of flexibility in metal forming.

1.2. Classification of flexibility in metal forming

There are many ways to classify forming processes, as well summarized in the reference by Groche et al. [52]. In the reference, traditional classifications for conventional forming processes are discussed in detail. For incremental bulk forming, the authors introduced new simplified criteria: stress system and deformation sequence (i.e. intermittent, continuous). In addition to several conventional classifications, they also introduced the initial workpiece shape to distinguish between incremental bulk metal forming processes with rotational tool motion. That is: Billet (brick shape or plug shape), Long product (bars or rods) and Rings.

For general incremental forming processes covering both sheet and bulk forming processes, a more appropriate criterion is required.

Halevi and Weill [62] proposed an interesting systematic classification procedure for selecting an appropriate metal forming process according to technical feasibility and economic optimization considerations. The method can also be applied to general incremental forming processes. The proposed process selection procedure takes into account:

1) Lot size (product quantity).
2) Part shape (complexity).
3) Achievable accuracy.
4) Material.

In this process selection methodology four basic shape complexity levels are distinguished in an effort to discretize geometrical capabilities. These levels correspond to parts that can be specified by a characteristic cross section and length (mono), parts that can be made with a simple die set with mono-directional kinematics (open), parts with undercuts (complex) and other geometries, typically containing enclosed volumes (very complex).

The technical and economic feasibility of a process to support the manufacture of small lot sizes on the one hand and more complex shapes on the other, appears to be a useful categorization approach to distinguish the flexibility of forming processes. As in conventional classification methods, part shaping capability is still the most important criterion. Lot size is a criterion that is strongly related to the need for dedicated tooling and set-up costs for a specific part geometry, and reflects the process capability to use generic tooling and flexible set-up techniques: processes that are facilitated by tools which can accommodate a broad range of geometrical part specifications are thus requiring low direct investment costs and setup times between batches of diverse products. The achievable accuracy and material constraints are reject criteria reflecting technological process capability considerations.

Halevi and Weill [62] refined the preference rules for the full taxonomy of manufacturing processes, including forming processes, based on process capabilities to shape products as well as quantity considerations.

Fig. 3 shows the flexibility level with respect to geometric complexity and economically feasible batch size that can be derived from the approach described by Halevi and Weill [62].

Differently from the categorization for selecting general basic forming process(es), classification of flexibility in forming depends rather on the way in which the material is formed, how some physical parameters are varied and how processes are operated in terms of process, machine, system and operation software. In addition to shape complexity and lot size, therefore, degree of freedom and variation of physical parameters can be added as major factors to influence flexibility as summarized in Fig. 4. That is, major influencing factors on flexibility in forming are;

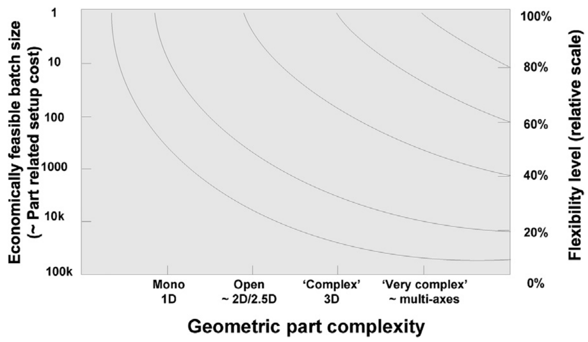

Fig. 3. Flexibility level with respect to lot size and shape complexity.