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Hybrid processes in manufacturing

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ABSTRACT

Hybrid manufacturing processes are based on the simultaneous and controlled interaction of process mechanisms and/or energy sources/tools having a significant effect on the process performance. These processes have a large influence on the processing/manufacturing characteristics resulting in higher machinability, reductions of process forces and tool wear, etc. Due to the combined action of processes, it also has an important – and most of the time – positive effect on the surface integrity of machined parts. This paper gives a definition and classification of hybrid processes, followed by a description of principles and future perspectives, benefits on productivity, effects on surface quality and applications of common hybrid processes.

1. Introduction

Hybrid production/manufacturing means the combination of processes/machines in order to produce parts in a more efficient and productive way. As stated in [175], a general objective of hybrid manufacturing is the "1 + 1 = 3"effect, meaning that the positive effect of the hybrid process is more than the double of the advantages of the single processes. Hybrid technologies give new possibilities to machine/process materials or shapes which could not be manufactured before or at lower cost. Within the domain of manufacturing technology, the term "hybrid" is often used to identify processes/products that combine several kind of technologies. According to Schuh et al. [175], "hybrid" can have several meanings: (1) combination of different active energy sources which act at the same time in the processing zone (e.g. laser assisted turning); (2) processes which combine process steps that are usually performed in two or more process steps (e.g. integration of component manufacturing and functional surface structuring or the integration of production of the semi-finished product and its bending in curved profile extrusion); (3) hybrid machines, integrating different processes within one machining platform (e.g. mill-turn centers); and (4) products having a hybrid structure or hybrid function (e.g. metal plastics composites components). Today, the term "hybrid processes" is often used to name processes belonging to the different groups presented. For example, laser assisted turning (combination of active principles) and multi-tasking machines (hybrid machines) are often entitled as hybrid processes. Also in literature, several descriptions of the term of "hybrid processes" are found. Rajurkar et al. [154] defines hybrid machining as a combination of two or more processes to remove material. These hybrid processes are developed to enhance advantages and to minimize potential disadvantages found in an individual technique. Kozak et al. [95] writes that the performance characteristics of hybrid machining processes must be considerably different from those that are characteristic for the component processes when performed separately. In hybrid machining (removal) processes, there are generally two categories: processes in which all constituent processes are directly involved in the material removal and processes in which only one of the participating processes directly removes the material while the other only assists in removal by positively changing the conditions of machining.

In [132], Nau et al. define hybrid production processes as such that different forms of energy or forms of energy caused in different ways respectively are used at the same time at the same zone of impact as it is the case in laser-assisted machining. Hybrid production processes are also defined as the combination of effects that are conventionally caused by separated processes in one single process at the same time like in grind-hardening.

Also, in metal forming the term "hybrid" is used in a broad definition. The term is used to characterize hybrid products which are manufactured by different materials like in cold forging of composites made from two more different alloys. It is also used to identify hybrid processes which are originally separately driven processes, such as combined hot extrusion, electromagnetic forming and hot sheet metal forming [66,67,136].

In this paper, a precise definition and a classification of "hybrid processes" is given (Section 2), followed by a description of some

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important hybrid process technologies (Sections 3 and 4), focusing on the benefits on productivity (processing speed, surface quality, etc.). The work presented here is a result of discussions among researchers within the CIRP collaborative working group on Hybrid Processes of the International Academy for Production Engineering (CIRP). Within this collaborative working group (CWG), an extended questionnaire has been conducted leading to an extensive document describing the state-of-art in various hybrid process technologies [108].

The need (and potential) for hybrid processes is also driven by resource and energy considerations [201] and by industry demands. The design of highly engineered mechanical products such as gas turbines, advanced automotive systems and heavy off-road equipment, often rely on advanced materials to achieve required performance characteristics. Many parts require high strength materials, exhibiting high temperatures or where formability should be reduced, requiring new processing technologies. In aerospace applications, this represents continued evolution and use of materials like powder nickel and cobalt alloys, high performance ceramics, and various emerging and yet to be defined advanced composite systems.

From a manufacturing perspective, the process technologies required to transform these materials into final products have become increasingly challenging. The "strength-at-high-temperature" characteristics that make some alloys superior in service, or the unique characteristics that make other alloys lightweight, make them extremely difficult to machine by traditional methods. Sensitivity to near-surface damage related to machining processes is also a factor critical to component performance and service life.

2. Definition and classification of hybrid processes

Based on numerous discussions held within the CIRP collaborative working group on hybrid processes, the following definition has been put forward:

> "**Hybrid manufacturing processes are based on the simultaneous and controlled interaction of process mechanisms and/or energy sources/tools having a significant effect on the process performance**".

The wording "simultaneous and controlled interaction" means that the processes/energy sources should interact more or less in the same processing zone and at the same time.

Two distinct examples of hybrid processes are given to better explain what a hybrid process means. First, laser assisted cutting, where the laser beam is directly focused in front of the cutting tool, resulting in easier machining and higher process performance (Fig. 1).

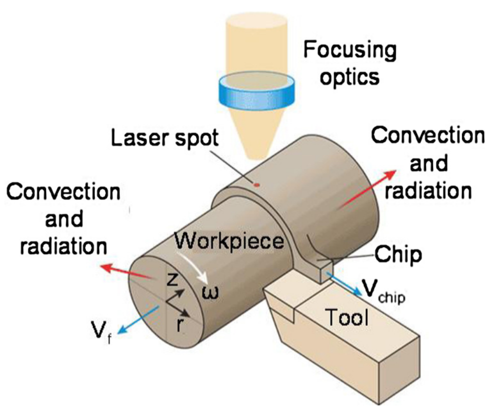

Fig. 1. Principle of laser assisted turning [177].

In this process, the main material removal mechanism is still the one occurring in conventional cutting, but the laser action softens the workpiece material, so machining of high alloyed steels or some ceramics becomes easier. It is only by applying the laser energy and the mechanical cutting energy at the same time ("1 + 1 = 3 effect") that more efficient machining becomes possible. Due to the softening effect, the process forces decrease drastically and often better surface quality can be obtained.

A second example in the area of forming is curved profile extrusion (CPE) [77], where extrusion and bending is combined within a unique new process. In comparison to the traditional processing route for manufacturing of curved profiles (Fig. 2), where first the straight profile is extruded and then in a second process bended, in CPE, the extruded profile passes through a guiding tool, moveable by a linear axes system, naturally bending the profile during extrusion. Thus, the material flow in the extrusion die is influenced by the superimposed bending moment of the guiding tool and the additional friction force in the bearing areas. Consequently, the material is accelerated at the outside and decelerated at the inside of the profile so that a controlled curvature results from this differing material flow. Due to the bending during extrusion within the die, this new forming process causes no cross-sectional distortion of the profile, no spring back, and nearly no decrease in formability. Compared to warm bending tests, process forces could be drastically reduced to 10–15% of the bending force that would be required if only warm bending would have been applied.

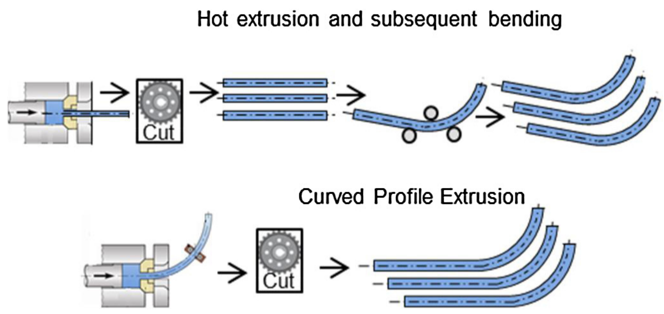

Fig. 2. Comparison of traditional manufacturing of curved profiles versus curved profile extrusion (hybrid).

The development and application of a hybrid process should be as such that it enhances the advantages and minimizes the potential disadvantages found in the individual techniques [154]. The simultaneous effect of process technologies enhances the productivity (e.g. lower process forces, less tool wear) and/or makes processing of materials possible which cannot be manufactured by a single (conventionally applied) process [105]. Besides the above mentioned productivity measures, the simultaneous combination of processes and or energy sources also has an effect on surface integrity [107]. The latter is sometimes neglected in formulating the potentials of hybrid processes.

A combination of processes does not necessarily means that all productivity measures are enhanced. Sometimes, one only aim a better chip breakage (e.g. media assisted cutting), while in other combinations, better machinability is aimed for (e.g. laser assisted cutting) [134].

Fig. 3 gives a further classification or grouping of hybrid processes and some examples. The first group (I) contains processes where two or more energy sources/tools are combined and have a synergetic effect in the processing zone. A further classification is made in "Assisted Hybrid Processes" (I.A) and "Mixed or Combined Processes" (I.B). In assisting processes, a main process (material removal, forming, etc.) is defined by the primary process. The secondary process only assists, while in pure hybrid processes, several processing mechanisms (originating from the different processes) or even new mechanisms are present. In the authors opinion, media assisted machining processes (high pressure jets, cryogenic cooling) are also defined as assisted hybrid processes, where the amount of energy applied for the secondary processes (jet) is relatively high compared to the