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A NOVEL DESIGN OF CRTM MOLD BY USING TRIZ SEPARATION PRINCIPLES

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Abstract: *The CRTM (compression resin transfer molding) also known as injection-compression molding (I-CM), is a variant of RTM (resin transfer molding). In this process, the upper part of the mold is rigid and moveable in order to increase the fiber volume fraction and to improve the surface quality of the part. Moreover, it minimizes the entrapment of air pockets, by applying a compression force that squeezes and displaces all air and volatiles bubbles out through the vent gate. Also, the CRTM reduces the injection pressure, fill time and gives answer to limitation of in-plane impregnation velocity as compared to RTM. Although its advantages, the CRTM needs a high force to displace the moveable upper mold and to better compress the preform, this leads to increase the cost equipment and to deform mold walls which influences the part quality. The main objective of this paper is to propose and discuss a new design of the CRTM mold, allowing at the same time to facilitate the manufacturing process, in particular to reduce the cycle time, the cost investment and to respect the material's health by obtaining a part with minimum defects. This innovation is achieved by using the TRIZ (theory of inventive problem solving) separation principles in order to eliminate the physical contradictions that exist between the different parameters governing the CRTM process.*

Key words: *RTM, CRTM, TRIZ, Physical contradictions, Separation principles..*

1. INTRODUCTION

Composite materials have gained attention and won competitiveness against others traditional metals. Recently, they have been widely applied in many fields ranging from the heavy industries, like as aeronautic, automotive and marine to the common consumer product such as sporting goods. This new high status is given to the composite materials by the virtue of their superior mechanical performance, lightweight and good resistance to corrosion and fatigue [1]. There are five major families for manufacturing composite components: autoclave, hand lay-up, filament winding, pultrusion, and liquid composite molding (LCM) [2]. Due to its capacity to significantly reduce the release of volatile organic compounds (VOCs) to the atmosphere, the LCM manufacturing processes have gained attractiveness and popularity compared with current methods of open molding processes. They have also been created to overcome the intrinsic weaknesses of autoclave draping processes such as: their high tooling cost and their long cycle time. The term LCM refers to composite manufacturing processes in which a fibrous preform material is placed into a mold cavity and a thermosetting resin with a relatively low viscosity is impregnated the preform until all empty spaces between the fibers are filled, and finally cured to create a polymeric composite structure [3]. The LCM family encompasses a growing list of mold filling process variants distinguishable from each other by the nature of the mold used and the manner of the filling phase. The LCM mold is divided in two parts, the lower part of the mold is always rigid but the upper part is possibly be rigid, like in RTM, CRTM and flexible injection, semi flexible (RTM-light) or flexible such as in VARTM, VARI and LRI, while the resin can be introduced using a combination of a positive injection pressure (use of an injection machine), vacuum infusion (use of a vacuum pump), and possibly assisted by the compaction force.

The Resin transfer molding (RTM) is one of the most recognized LCM processes, it was adopted for composite manufacturing in the mid-1980s. RTM manufacturing includes several steps. It begins by placing a dry fibrous reinforcement inside a rigid mold, closing the mold, injecting a liquid resin, curing the resin and finally demolding the part. Due to its several advantages [4], RTM has received the most industrial attention [5, 6]. The most important objective of this process is to reduce the time it takes to fill the mold with resin. This will increase the production rate and reduce manufacturing costs and also ensure that the fabric preform is completely saturated before the resin starts to gel [7]. These objectives are well achieved in the manufacturing of complex small to mid-size products. However, The conventional RTM processes usually have limitations in fabrication large parts due to the cost investments, pressure equipment, and the process time, that dramatically increasing proportional to the surface area of composite structures [8]. Furthermore, a problem arises with RTM for composite parts with a high fiber content. Indeed, the permeability of the fibrous reinforcement drops drastically with an increase of the fiber content. Consequently, mold filling is completed after a much longer period of time, resulting not only in a low overall throughput of the process, but sometimes in a non-uniform impregnation of the reinforcement. Over the years, several modifications of the resin transfer molding (RTM) process have been proposed to enhance the fiber volume fraction and reduce the mold filling time or molding pressure. One of the effective methods is to incorporate the method of compression into the RTM.

The CRTM, compression resin transfer molding, also known as injection-compression molding (I/CM) [7, 8], is the first variant of compression techniques. In this process, the upper part of the mold is rigid and moveable in order to increase the fiber volume fraction and to improve the surface quality of the part. Moreover, it minimizes the entrapment of air pockets, by applying a compression force that squeezes and displaces all air and volatiles bubbles out through the vent gate. Also, the CRTM reduces the injection pressure, fill time and gives an answer to limitation of in-plane impregnation velocity as compared to RTM. The steps for fabricating the composite part by CRTM are described in details in [9]. Although its advantages, the CRTM needs a high force to displace the moveable upper mold and to better compress the preform, this lead to increase cost equipment and to deform mold walls which influence the part quality.

These limitations can be minimized by using an upper mold made of several pieces that can be articulated separately. This variant called ACRTM (Articulated compression resin transfer molding) [10]. Despite these advantages [11], this process requires a perfect manufacturing of these pieces, which increases significantly the cost equipment. Another disadvantage, as these pieces are articulated separately, the resin can enter and gel between them, also the air can get into the mold cavity, which leads to dramatically reduce the part performances. Ruiz proposed another process in 2003, called flexible injection [12], this process is composed of two rigid halves mold separated by a flexible membrane. The first chamber contains the fiber preform impregnated by a resin and the second chamber is filled with a compaction fluid in order to apply a uniform pressure on the first chamber, which leads to compact the preform and to increase the resin impregnation velocity [13]. Chang propose another variant of VARTM called vacuum-assisted compression resin transfer molding [14], it has been developed to reduce the mold filling time, injection pressure and cleaning mold time compared with resin transfer molding. The vacuum-assisted compression resin transfer molding utilizes an extra elastic film placed between the upper mold and the mold cavity compared with resin transfer molding. Through the stretchable film, the state of the fabric stack is under control.

During resin injection, a loose fiber stack is present and then resin is easily introduced into the cavity. Once enough amount of resin is injected, a compression pressure is applied on the film that compacts the preform and drives the resin through the preform. Some shortcomings are inevitable including the edge effect and excess of injected resin. More resin leads to a longer injection and compression phases and more wastes. The progressive compression method (PCM) [15], can be seen as the combination of the flexible injection, the articulated compression resin transfer molding and the vacuum assisted compression resin transfer molding. In PCM, the flexible membrane is divided into several segment, each one is controlled individually. This process was essentially proposed to reduce the filling time and to improve the material waste [16]. All these processes were tried to make the trade-offs between the ability to fabricate large composite parts, cost investment of the heavy press and the pressure equipment, raw materials waste, deformation of the mold walls, the perfect manufacturing of the rigid articulated segment and the accuracy and the control complexity of the segmented membrane in addition to the excess of injected resin and the edge effect and other phenomena that appear due to these imperfections. The main objective of this paper is to propose and discuss a new design of CRTM mold based on the application of the TRIZ theory, which contains many powerful tools used to solve such contradictions in an innovative way without making the compromises.

2. TRIZ theory

TRIZ 'Teoriya Reshniya Izobretatelskikh Zadatch' is the Russian acronym for the Theory of Inventive Problem Solving, it was created and developed by the Russian engineer G.S. Altshuller and his colleagues in 1946 in the former USSR. TRIZ is a human-oriented knowledge–based systematic methodology of inventive problem solving [17]. It is based on the analysis of millions of patents [18], and states that:

- Problems and solutions were repeated in industry and science.
- Patterns of technical evolution were repeated in industry and science.
- Innovations used scientific effects outside the areas in which they were developed.

TRIZ was initially the goal, to facilitate and improve the resolution of the technological problems [19, 20]. Over the past years, TRIZ has used in different sectors, including electrical Engineering [21], chemical engineering [22], automotive sector [23], mechanical field [24], environmental area [25], and business and organization management field [26]. Due to these large scope of applications, nowadays TRIZ has become as one of the most powerful, popular innovative method. Figure 1 illustrates TRIZ theory methodology.

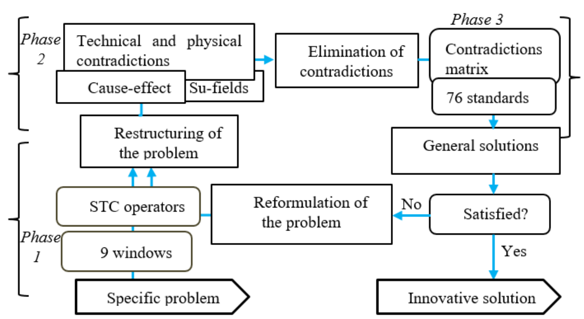

Fig. 1. Components of TRIZ theory methodology.

This method is based on three main phases [27-30]:

Phase 1: Description and understanding of the specific problem

This phase is essential to better understand and formulate correctly the problem, it's applicable in four steps:

- The description of the project.
- The analysis of the system.
- The identification of the problems.
- Ideal final result formulation.

During this phase, it's recommended to use some rules and apply the TRIZ tools such as, smart little people method, size-time-cost operators and the nine windows tool that allow us to avoid psychological inertia.

Phase 2: Formulation and modeling of the problem

It is used to find the contradictions between the parameters of the system by using the following tools.

- Cause-effect analysis.
- Technical and physical contradictions.
- Substances-Field Models (Su-Field analysis).
- Laws of engineering systems evolutions.

Phase 3: Generation of solutions

It allows to solve the previous contradictions and to generate models of solutions by using the following tools:

- 40 Inventive principles and Contradictions matrix.
- Separation principles.
- 76 standards.

3. DESCRIPTION AND UNDERSTANDING OF THE SPECIFIC PROBLEM.

3.1 External functional analysis

This tool is used to understand why the system exist and to illustrate the relationship between the system and its external environment, in addition to identify the principal functions (PF) and the constraints functions (CF) related to the system [31]. The external functional analysis is applied according to the following four steps:

1. Identification of the elements of the external environment
2. Identification of the principal and the constraints functions (Octopus Diagram)
3. Characterization of the principal and the constraints functions.
4. Definition of the mission profile of the system.

Figure 2 shows external functional analysis of CRTM mold.

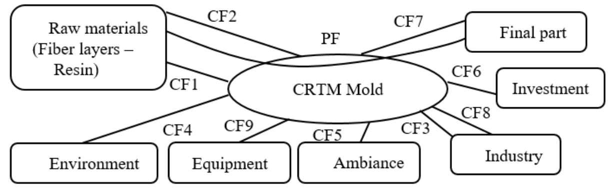

Fig. 2. External functional analysis of CRTM mold.

PF: Transform the raw materials into the desired final part.
CF1: Inject and quickly fill the mold without any resin leakage.
CF2: Compact uniformly the fibrous reinforcement.
CF3: Be profitable.
CF4: Resist to the aggressive environment (noise, dust, humidity and other industrial environments).
CF5: Do not pollute the environment (mechanical noise, Chemical emissions (styrene)).
CF6: Do not require a huge investment.
CF7: Give a good surface finish and close dimensional tolerances.
CF8: Satisfy the industry sector requirements.
CF9: Do not require a heavy equipment.

3.2 Structural decomposition

This tool is used to identify all system and subsystems components and their functions. Figure 3 presents the structural decomposition of CRTM mold

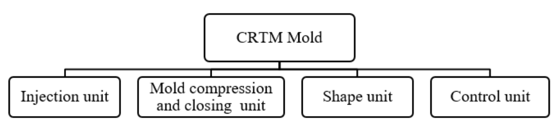

Fig. 3. Structural decomposition of CRTM mold.

Compression and closing mold unit: It is used in order to apply a pressure or force usually on the upper rigid half mold, which leads in the first stage, to close the mold and prevent any air-resin leakage. In the second stage, this unit compacts the fibrous reinforcement layers for increasing its volume fraction.
Shape unit: Includes two rigid sides of the mold, carved inside them the part shape, it may also contain the inlet and the outlet gates.
Control unit: Includes all tools used to measure and control CRTM process variables, as well as

to give all required information about the system evolution.

Injection unit: Permits to store and to transfer the resin and additives from their separate tanks to the mold cavity.

3.3 Ideal Final Result formulation

In the present situation, the ideal CRTM mold, will be a mold capable to produce large complex part that have high mechanical performance suitable for aeronautic applications. Furthermore, this process should reduce injection pressure and process time without the need to use a huge and heavy compression press. Satisfying the latter requirements allow to this new design of CRTM mold to be also used widely and efficiently to fabricate automotive components.

4. CAUSE-EFFECT ANALYSIS

The cause-effect diagram is a TRIZ tool, used to identify the useful and harmful resources of the CRTM manufacturing process and its environment, as well as to find the contradictions and conflict links between all parameters mentioned above. Figure 4 illustrates the process of generating creative solutions by using cause-effect analysis.

In this article, we are focusing on the application of the cause-effect analysis methodology by using separation principles (path b). The cause effect diagram of CRTM process is presented in figure 5.

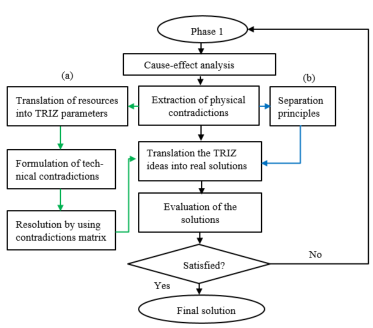

Fig. 4. Cause-effect analysis process (a) by using contradictions matrix (b) by using separation principles

4.1 Extraction of physical contradictions

A physical contradiction (PC) is a situation in which a component or an element in an engineering system present two contradictory values simultaneously [32, 33]. In physical contradictions, the conflict of demands is intensified to the maximum. Therefore, at first glance the physical contradiction appears inadmissible, absurd by definition [34]. In our problem, the physical contradictions are presented as follows:

PC1: The high compression force should exist to improve the fiber volume fraction, and short impregnation time, and should not exist to avoid mold walls deformation.

PC2: The high compression force should exist to improve the fiber volume fraction, and short impregnation time, and should not exist because it impedes the industry requirements.

PC3: The high compression force should exist to improve the fiber volume fraction, and short impregnation time, and should not exist to avoid high cost investment.

PC4: The high fiber volume fraction should exist to provide high mechanical performance; and should not exist because it impedes resin impregnation velocity.

PC5: The fabrication of large part should exist to satisfy the industry requirements, and should not exist because it impedes the short impregnation time.

PC6: The use of high injection pressure should exist to improve short impregnation time, and should not exist to avoid high cost investment.

PC7: The fabrication of large part should exist to satisfy the industry requirements (part dimension), and should not exist because it impedes the high compression force.

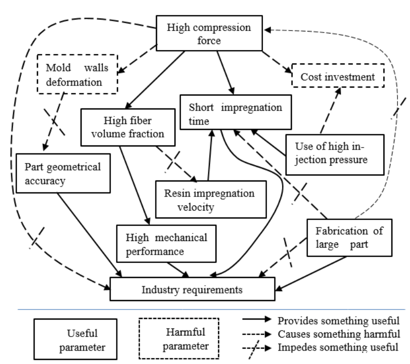

Fig. 5. Cause-effect analysis of CRTM process.

4.2 Separation principles

The physical contradiction could be removed by applying four "principles of separation" which are; separation in space, in time, separation within a whole and its parts as well as separation upon conditions [35, 36].

1. Separation in time: It is used when a system requires one situation value at one time and the opposite situation value at another time.
2. Separation in space: It exhibits when a system demands one solution value in one place and the opposite solution value in another place.
3. Separation on condition: It manifest when the two contradictory values are independent of time and place but they change according to the operating conditions. Therefore, under some conditions the system requires one value and under other conditions the system requires the opposite value.
4. Separation of contradictory properties between the whole and its parts: the whole system has a property value, while its components have the opposite property value.

These principles can be used independently or in combination. To solve a problem containing a physical contradiction, one should follow a simple routine [37]. The figure 6 presents a systematic methodology to determine the right separation principles to solve a given physical contradiction.

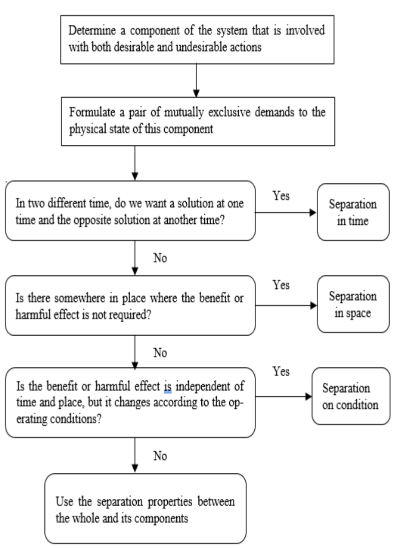

Fig. 6. Systematic methodology for selecting the separation principles

5. CONCEPTS GENERATION

The physical contradiction 1 (PC1) is solved by using the separation in space.
The use of the inventive principle: 1 "Segmentation" with the recommendations:

1. Divide an object into independent parts, and
2. Increase the degree of segmentation or fragmentation

Allow to generate two main concepts as depicted in the figures 7 and 8.
In the CRTM process, the mold cover is always made of a single rigid part. Thereby, the CRTM needs a high force to displace the moveable upper mold and to better compress the preform, this lead to increase cost equipment and to deform mold walls which influence the part quality. However, these limitations can be minimized by using an upper mold made of several pieces that can be articulated separately. This variant called ACRTM ("articulated compression resin transfer molding") [10].

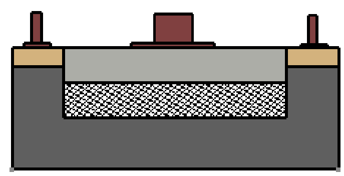

Fig. 7. The CRTM mold.

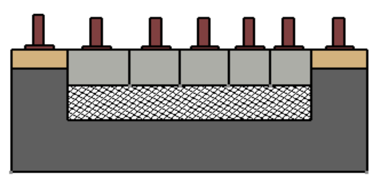

Fig. 8. The ACRTM mold.

The use of the inventive principle: 2 "Taking out or extraction" with the recommendation "Extract the only necessary part or property of an object", allows us to think to keep only the compression function and change the rigid half mold by the vacuum bag. The compression function is carried out by using a stationary powerful magnet like as neodymium iron boron magnets to guarantee the compression function without the need of heavy press. This process was proposed by Amirkhosravi in 2018, it is called magnet assisted composite manufacturing (MACM) [38] (see fig 9).

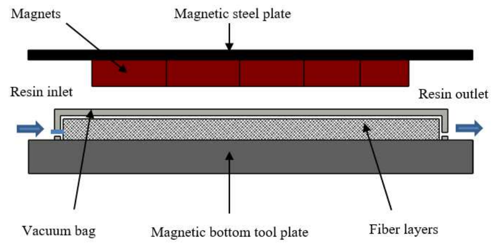

Fig. 9. The MACM mold components.

The physical contradiction 2 (PC2) is solved by the following inventive principles:
The use of the inventive principle: 15 "Dynamics" with recommendation "divide an object into parts capable to move relative to each other" permits to generate the process proposed by Chang, called "PCM: Progressive compression method" [15], as illustrated in the figure 10. This process belongs to the vacuum infusion processes (VIPs), as well as it's an evolution of the flexible injection process [12]. The PCM reduces the filling time compared to the vacuum infusion processes.

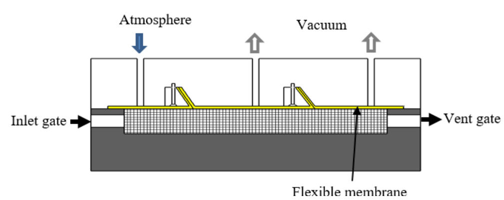

Fig. 10. The PCM mold [26]

The use of the inventive principle: 24 "Intermediary" with the recommendation "use an intermediary carrier article or intermediary process" leads to find the process proposed by Ruiz, called flexible injection [12, 13] as illustrated in the figure 11.

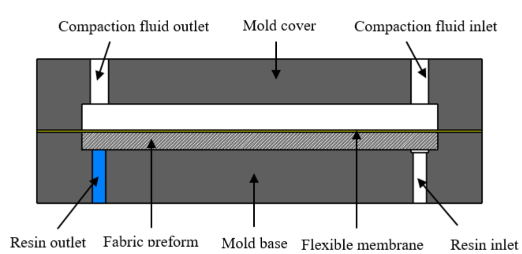

Fig. 11. Flexible injection mold components

The use of the inventive principle: 29 "Pneumatics and hydraulics" with the recommendation "Use gas and liquid parts of an object instead of solid parts (inflatable, filled with liquids, air cushions) allows to generate the concepts depicted in figures 12 and 13.

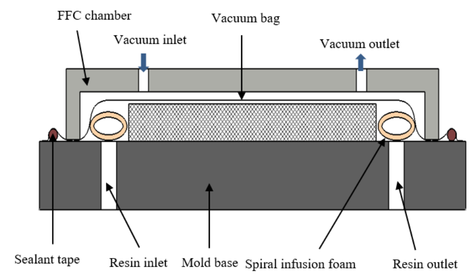

Fig. 12. The flow flooding chamber mold components [39].

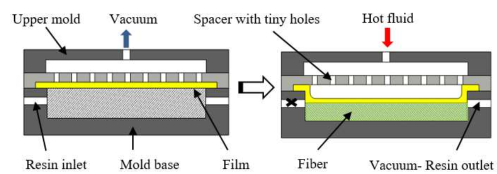

Fig. 13. The Schematic diagram for non-isothermal VACRTM [14]

The use of the inventive principle: 28 "Mechanics substitution" with recommendation "Use electric, magnetic and electromagnetic fields to interact with the object" allows us to propose a new variant of VARTM process called relaxation-compression resin transfer molding under magnetic field [40] as illustrated in the figure 14. In this process, we only use a single rigid side mold like as in the VARTM processes, that contains the fiber preform, and it covers by a flexible magnetic membrane, or by using a vacuum bag including a ferromagnetic sheet, gathered together by an effective glue. The magnetic field is controlled by the current intensity or by the separated gap between the coil and ferromagnetic membrane, so as to apply a magnetic force on the membrane and as a result, move it up to relax the preform or down in order to compress the fiber reinforcement. Which leads to speed up the impregnation velocity and increase the fiber volume fraction.

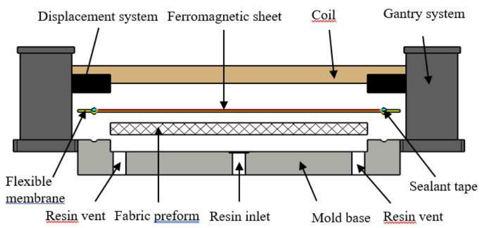

Fig. 14. Relaxation-compression resin transfer molding under magnetic field mold component.

The combination of the inventive principles 28 and 29 allow to propose a new variant of CRTM process. This new process is called magnetic compression resin transfer molding (MCRTM), it could be seen as the combination of the magnet assisted composite manufacturing and the flexible injection. Figure 15 illustrates the different components of MCRTM mold.

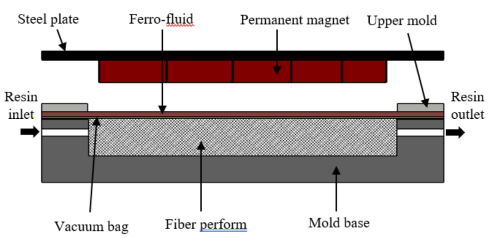

Fig.15. Magnetic compression resin transfer molding (MCRTM) mold component.

6. CONCLUSION AND OUTLOOK

In this paper two design of CRTM (compression resin transfer molding) mold were proposed based on the application of TRIZ separation principles, that are used to eliminate the physical contradictions existed between the current CRTM mold variants. The relaxation-compression resin transfer molding under magnetic field and the magnetic compression resin transfer molding have a great potential to replace the current CRTM processes. To study and evaluate the efficiency of these new processes, we are currently working on the mathematical modeling and numerical simulation.

7. REFERENCES

[1] Chang, CY., Chen, WR.: Influence of processing variables on quality of unsaturated polester/E-glass fiber composites manufactured by double-bag progressive compression method. Adv Mech Eng.10, 1–9 (2018).

[2] Achim, V., Soukane, S., Gauvin, R., Trochu, F.: Simulation of articulated compression resin transfer molding. In: Proceedings of the 8th flow proc compos mats, pp. 232–330. 2006.

[3] Lopatnikov, S.: A closed form solution to describe infusion of resin under vacuum in deformable fibrous porous media, Modelling Simul. Mater. Sci. Eng. 12, S191–S204 (2004).

[4] Sozer, EM.: Manufacturing techniques for polymer matrix composites (PMCs), Woodhead Publishing Limited, Cambridge, 2012.

[5] Potter, K.: Resin transfer moulding, Chapman & Hall, London, 1997.

[6] Marsh, G.: Composites on the road to the big time? Reinforced Plastics 47(2):33–36 (2003).

[7] Wang, J.: Use of medial axis to find optimal channel designs to reduce mold filling time in resin transfer molding, Compos A Appl Sci Manuf 95(Supplement C):161–72 (2017).

[8] Song, H.: Study on high-speed RTM to reduce the impregnation time of carbon/epoxy composites, Composite Structures 119, 50–58 (2015).

[9] Seemann, WH.: Plastic transfer molding techniques for the production of fiber reinforced plastic structures, US Patent No. 4902,215, 1990.

[10] Choi, JH., Dharan, CKH.: Enhancement of resin transfer molding using articulated tooling, Polym. Compos 23(4), 674–681 (2002).

[11] Choi, JH., Dharan, CKH.: Mold fill time and void reduction in resin transfer molding achieved by articulated tooling. J Compos Mater 36, 2267–2285 (2002).

[12] Trochu, F., Soukane, S., Touraine, B.: Flexible Injection: A novel LCM technology for low cost manufacturing of high performance composites. Part II: Numerical model. In: Proceedings FPCM9. Montréal, Canada (2008).

[13] Ruiz, E., Briones, LR., Allard, É., Trochu, F.: Flexible injection: a novel LCM technology for low cost manufacturing of high performance composites. Part I: experimental investigation. In: Proceedings FPCM9, p. 34 (2008).

[14] Chang, CY.: Experimental analysis of mold filling in vacuum assisted compression resin transfer molding, J. Reinf Plast Comp 31,1630–1637(2012).

[15] Chang, C.Y.: Numerical study on filling process in progressive compression method. Adv. Compos. Mater 28, 37–51 (2017).https://doi.org/10.1080/09243046.2017.1405598
[16] Chang, C.Y.: Numerical simulation of double-bag progressive compression method of resin delivery in liquid composite moulding, Plastics, Rubber and Composites, DOI: 10.1080/14658011.2019.1647387
[17] Savranksy, S.D.,: Engineering of creativity: Introduction to TRIZ methodology of inventive problem solving. CRC Press, Boca Raton, Florida (2000).
[18] Ilevbare, M., Probert, D., Phaal, R.: A review of TRIZ, and its benefits and challenges in practice; Technovation 33, pp. 30-37 (2013).
[19] Altsthuller, G. S.: The innovation algorithm; triz, systematic innovation and technical creativity. Technical Innovation Center Inc.,Worcester, MA (1999).
[20] Mansoor, M., Mariun, N., Toudeshki, A., Wahab, N.I.A., Mian, A.U., Hojabri, M.: Innovating problem solving in power quality devices: a survey based on dynamic voltage restorer case. Renew Sustain Energy Rev. 70, 1207–1216 (2017).
[21] Mansoor, M., Mariun, N., Toudeshki, A., Wahab, N.I.A., Mian, A.U., Hojabri, M.: Innovating problem solving in power quality devices: a survey based on dynamic voltage restorer case. Renew Sustain Energy Rev. 70, 1207–1216 (2017).
[22] Abramov, O., Kogan, S., Mitnik-Gankin, L., Sigalovsky, I., Smirnov, A.: TRIZ-based approach for accelerating innovation in chemical engineering. Chemical Engineering Research and Design 103, 25-31(2015).
[23] Azammi, AMN., Saquan, SM., Ishak, MR., Sultan, MTH.: Conceptual design of automobile engine rubber mounting composite using TRIZ-Morphological chart-analytic network process technique. Defence Technology, vol. 14, no. 4, pp. 268-277 (2018).
[24] Cempel, C.: Application of TRIZ approach to machine vibration condition monitoring problems. Mechanical Systems and Signal Processing 41, 328–334 (2013).
[25] Zhang, J., Shang, J.: Research on developing environmental protection industry based on TRIZ theory. Procedia Environmental Sciences 2, 1326-1334 (2010).
[26] Navas, H. V. G., Tenera A. M. B. R, Machado, V. C.: Integrating TRIZ in project management processes: an ARIZ contribution. Procedia Engineering. Elsevier V./issue 131C. p. 224 – 231(2015). DOI: 10.1016/j.proeng.2015.12.381.
[27] Zouaoua-ragab, D.: Lois d'evolution de TRiZ pour la conception des futures generations des produits : Proposition d'un modele. PhD Thesis Arts and Crafts ParisTech, 2012.
[28] Ilevbare, M., Probert, D., Phaal, R.: A review of TRIZ, and its benefits and challenges in practice; Technovation 33, pp. 30-37 (2013).
[29] Fey, V.: Dilemma of a Radical Innovation - A New View on the Law of Transition to a Micro-Level. TRIZ journal (1999).
[30] Domb, E., Miller, JA.: Applying the Law of the Completeness of a Technological System to Formulate a Problem. TRIZ journal (2007).
[31] Belu, N., Rachieru, N., Militaru, E., Anghel, D.: Application of FMEA method in product development stage. Academic Journal of Manufacturing Engineering, 10(3), 12-19 (2012).
[32] Ko, YT.: Modeling a hybrid-compact design matrix for new product innovation. Computers and Industrial Engineering, 107, 345–359 (2017).
[33] Dubois, S., Eltzer, T., De Guio, R. : A dialectical based model coherent with inventive and optimization problems. Computers in Industry, 60(8), pp.575–583 (2009).
[34] Altsthuller, G. S.: Creativity as an exact science. Gordon and Breach Scientific Publishers, New York (1984).
[35] Orloff, M.: Inventive Thinking through TRIZ: A Practical Introduction. 2nd edn. Springer, Berlin (2003).
[36] Pokhrel, C., Cruz, C., Ramirez, Y., Kraslawski, A.: Adaptation of TRIZ contradiction matrix for solving problems in process engineering. Chemical Engineering Research and Design. Vol.103, 3–10 (2015).
[37] D, Clausing., V, Fey.: Effective innovation: The development of winning technologies, ASME Press, New York (2004).
[38] Amirkhosravi, M.; Pishvar, M.; Altan, M.C.: Improving laminate quality in wet lay-up/vacuum bag processes by magnet assisted

composite manufacturing (MACM). Compos. Part A Appl. Sci. Manuf. 98, 227–237 (2017).

[39] Alms JB, Advani SG. Simulation and experimental validation of flow flooding chamber method of resin delivery in liquid composite molding. Compos Part A – Appl Sci Manuf 38(10), 2131–41 (2007).

[40] Ouezgan, A., Adima, S., Maziri, A., Mallil, E.H., Echaabi, J.: An Innovative Methodology to Design LCM Mold for Aeronautic and Automotive Industries, Springer International Publishing, (2019)

Un nou concept al matrițelor CRTM utilizând principiile de separare TRIZ

Rezumat: CRTM (formarea prin transfer de rășină sub compresie) cunoscută și sub numele de formare prin injecție-compresie (I-CM), este o variantă a RTM (formarea prin transfer de rășină). În acest proces, partea superioară a matriței este rigidă și mobilă pentru a crește fracțiunea volumului fibrei și pentru a îmbunătăți calitatea suprafeței piesei. Mai mult, reduce la minimum retenția buzunarelor de aer, prin aplicarea unei forțe de compresie care drenează și deplasează toate bulele de aer și volatile prin poarta de aerisire. De asemenea, CRTM reduce presiunea de injecție, timpul de umplere și oferă răspuns la limitarea vitezei de impregnare în plan comparativ cu RTM. În ciuda avantajelor sale, CRTM are nevoie de o forță mare pentru a deplasa matrița superioară mobilă și pentru a comprima mai bine preforma, acest lucru duce la creșterea costurilor echipamentului și la deformarea pereților matriței care influențează calitatea piesei. Obiectivul principal al acestei lucrări este de a propune și discuta un nou concept al matriței CRTM, permițând în același timp facilitarea procesului de fabricație, în special reducerea timpului ciclului, a costurilor de investiție și respectarea sănătății materialului prin obținerea unei piese cu defecte minime. Această inovație se realizează prin utilizarea principiilor de separare TRIZ (teoria rezolvării inventive a problemelor) pentru a elimina contradicțiile fizice care există între diferiții parametri care guvernează procesul CRTM.

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