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CLINCHING TECHNOLOGY IN THE AUTOMOTIVE INDUSTRY

TECHNOLOGIA POŁĄCZEŃ PRZETŁACZANYCH W PRZEMYŚLE MOTORYZACYJNYM

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Summary

The technology of sheet metal joining by clinching has been presented. The clinching is a process of joining material layers with the use of plastic deformations. The process of forming a joint by classic shaping has also been shown. Successive phases of forming a clinched joint during the sheet metal joining process have been characterized. Joint quality assessment methods and example applications of clinched joints have been described.

At present, tools of various designs are available for the forming of joints of this type. In most cases, a punch and a round solid die with an axially symmetrical profile are used. Other die design versions make it possible to reduce the joint-forming force to a significant degree. In the article, attention has been directed to various designs of the dies suitable for such an application and to the possibility of joining not only metallic materials but also metal and composite combinations. The possibilities of making hybrid (i.e. glued and clinched) joints have been described as well.

Moreover, new research directions and the development of unconventional clinching technology solutions have been characterized, with highlighting the use of clinched joints in the thin-walled structure assembly processes in the production of motor vehicles. The main directions of automatizing the process of assembling sheet metal structures by clinching have been discussed. Examples of motor vehicle body components with clinched joints have been presented.

Keywords: clinched joints, clinching, sheet metal joining, development of joining methods

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Streszczenie

W publikacji przedstawiono technologię łączenia blach za pomocą przetłaczania (ang. *clinching*). *Clinching* to proces scalania warstw materiału z udziałem odkształceń plastycznych. Przedstawiono przebieg procesu formowania złącza w klasycznej odmianie kształtowania. Scharakteryzowano fazy formowania przetłoczenia w trakcie łączenia blach. Opisano metody oceny jakości wykonania złączy, a także przykłady ich zastosowania.

Obecnie istnieją różne konstrukcje używanych narzędzi, do formowania tego typu złączy. Najczęściej stosowanymi narzędziami są stempel, oraz matryca okrągła i niedzielona o zarysie osiowo-symetrycznym. Inne odmiany konstrukcji matryc pozwalają na znaczne obniżenie siły kształtowania złącza. W pracy zwrócono uwagę na rożną konstrukcję możliwych do zastosowania matryc, możliwość łączenia nie tylko materiałów metalicznych ale także kombinacji metalicznych z kompozytowymi. Opisano możliwości tworzenia złączy hybrydowych tj. klejowo-przetłaczanych.

Ponadto scharakteryzowano nowe kierunki badań, rozwój niekonwencjonalnych rozwiązań technologii przetłaczania. Zwrócono uwagę na zastosowanie połączeń *clinching* w procesach montażowych cienkościennych konstrukcji podczas wytwarzania pojazdów samochodowych. Omówione zostały kierunki automatyzacji procesu montażu konstrukcji blaszanych z udziałem przetłaczania. Przedstawiono przykłady elementów nadwozi samochodowych w których stosowane są złącza *clinching*.

Słowa klucze: połączenia przetłaczane, clinching, łączenie blach, rozwój łączenia

1. Introduction

No motor vehicles could be designed and manufactured if adequate technologies of assembling separable and inseparable joints were unavailable. The joining of individual vehicle body components makes it possible to create a spatial structure that could not only meet design and operation requirements but be also manufactured in a cost-effective way.

The present-day form of motor vehicles' bodies is a result of many changes that took place for decades in the development of such vehicles. In the automotive industry, much effort is made to minimize the consumption of vehicle-powering fuels [1]. In consequence, newer and newer vehicle body shapes and materials used to manufacture the bodies are appearing (Fig. 1). The demand for construction materials with raised strength and performance characteristics, capable of meeting increasingly stringent requirements, is growing from year to year [2]. The dynamic development of new technologies, including material engineering, puts the automotive industry in a completely new situation. The greatest progress may be observed in the area of sciences of the technologies and many new materials are appearing. The new materials, in turn, generate the need to develop new material-joining technologies [3-6].

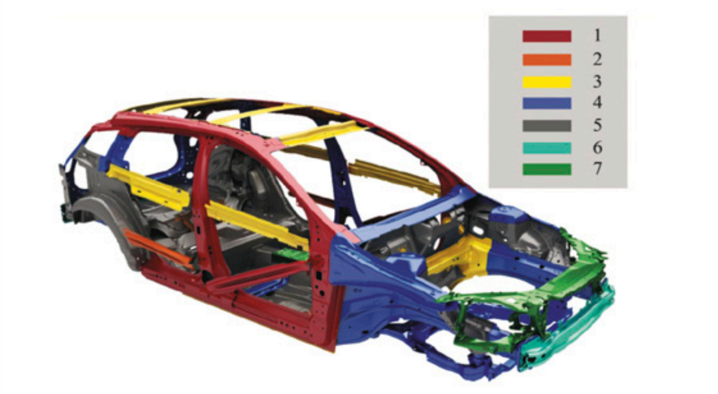

Fig. 1. An example of using different construction materials for motor vehicle body components: 1 – magnesium alloys; 2 – aluminium alloys; 3 – low-carbon deep-drawing steels; 4 – higher-strength steels HSS; 5 – high-strength steels; 6 – very high-strength steels; 7 – ultrahigh-strength steels

The present-day engineer faces the problem of assembling vehicle components from new materials, often of different types. These factors define the specificity of the assembly process. It may be confidently said that the manufacturing of motor vehicles in the contemporary world actually means automatized environment-friendly mass production [7]. The today's production philosophy comes down to the manufacturing of products in such a way that the environmental impact would be reduced to a minimum. The "white" (or "sustainable") assembling technologies are being developed [8, 9]. The process and product innovations bring about specific design and process changes. In result of increasing pressure on ecological and economic aspects, automotive manufacturers revise their approach to the use of joining technologies in the manufacturing of parts from new materials (Fig. 2).

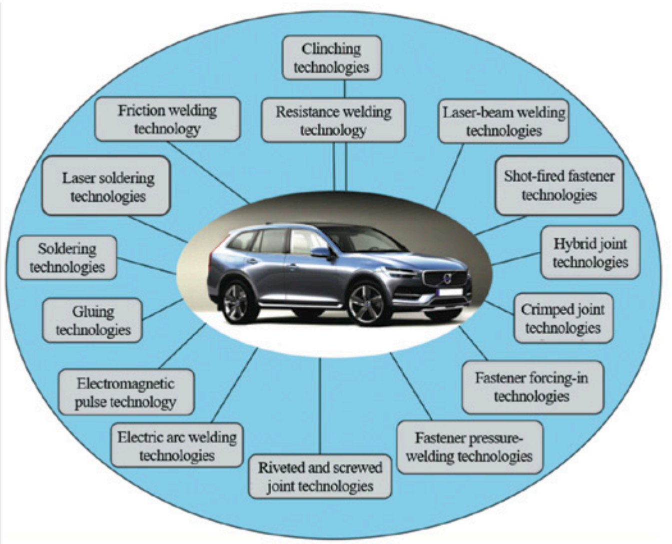

Fig. 2. Joining technologies used in the automotive industry

By 2018, the greatest impact on the development of the automotive industry will be exerted by the actions related to the development and launching of new products and the development of new technologies (Fig. 3), according to KPMG's Global Automotive Executive Survey [10]. In 2010, the use of pressure welding in the automotive industry declined in favour of laser-beam welding and joining by plastic working, including clinching (Fig. 4) [11]. This is expected by many manufacturers to bring economic benefits.

Fig. 3. Forecasted share of the actions that have an impact on the development of the automotive industry

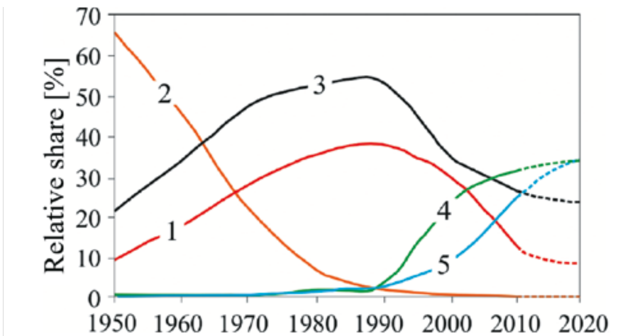

Fig. 4. Share of individual joining techniques used for the production of motor vehicle bodies: 1 – MIG/MAG welding; 2 – gas brazing; 3 – resistance welding; 4 – clinching; 5 – laser-beam welding (based on: IWU Fraunhofer Institute)

This article shows the possibilities of using the clinching technology, its development directions, and the directions of new research works in this field. The process of forming a clinched joint ("CL joint") has been briefly described. The current situation in the field of using the clinched joint solutions in the automotive industry has been reviewed.

2. The method of material joining by clinching

The shaping of a joint of the type under consideration is similar to the press forming: it is a process of cold forming of a very small area of the sheet metal parts being joined together, carried out with the use of a punch and die set. Before the joint is actually shaped, the sheet metal blanks to be joined together are clamped, i.e. pressed against the die surface (Fig. 5).

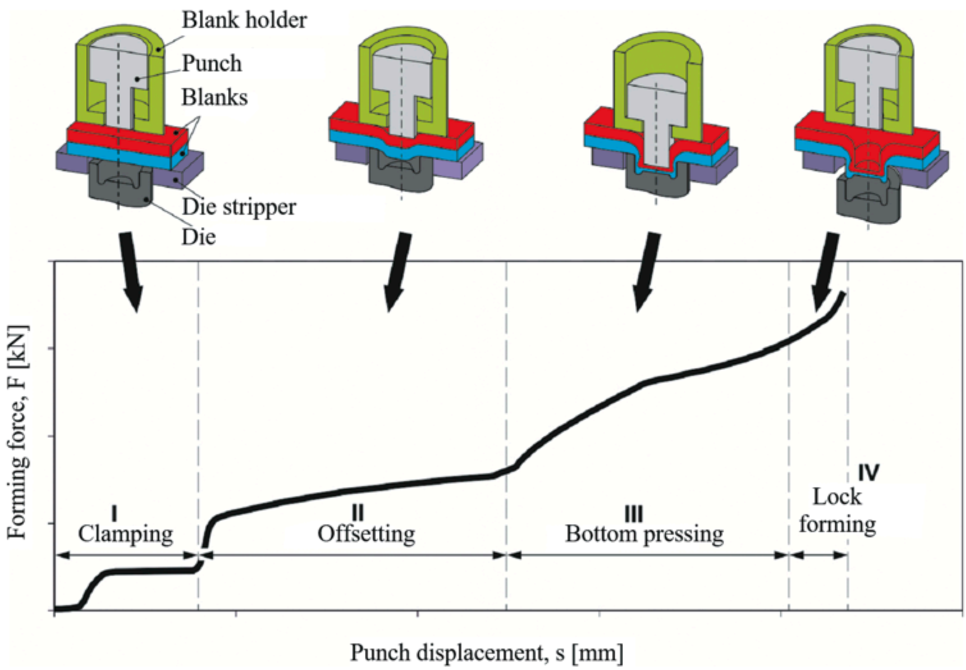

Fig. 5. The course of the process of forming a clinched joint and a forming curve at successive process stages

The clamping is to ensure appropriate metal flow during the forming process. The clamping (blank holding) force can be adjusted by selection of the force-deflection curve of the elastomer ring or spring (Fig. 6a). During the joining process, the punch is pressed against the blanks at the joint-forming place. The material is gradually forced into the die impression until the lower sheet leans against the impression bottom. At that time, the material begins to fill the free side space between the punch and die. When the free space filling is completed, intensive pressing of the sheet impression bottom takes place. At this stage, a lock is formed by special shaping of the sheet material for the parts to be clinched together (Fig. 6b). Apart from the geometry and shape of the lock, the structural changes in the material of the parts having been clinched have also an impact on the strength of the joint.

When a round die and punch is used to make the joint, the quality of the latter is considered acceptable if the cohesion of material of the two sheet metal layers being joined has not been lost. An exception is the technology variant where a rectangular clinched joint is made with a notch being intentionally formed along two edges of the joint [12]. Such a technology allows for somewhat bigger differences in the thickness and material type of the sheet metal parts to be joined. The clinched joints with a notch show a lower strength in comparison with round joints formed with the use of solid dies (Fig. 7). Moreover, the use of unlimited force values results in excessive loads and the loads applied cyclically may cause damage to the joint-forming tool (Fig. 8).

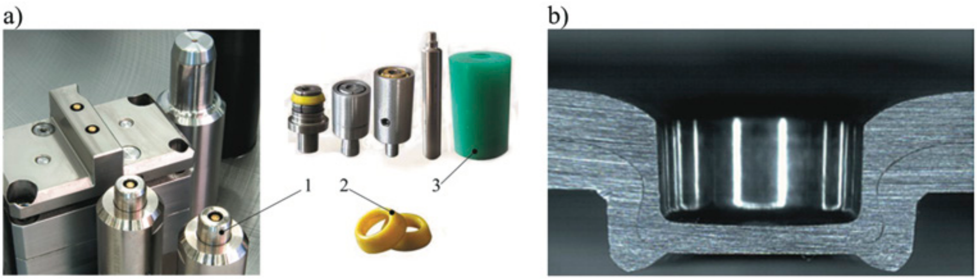

Fig. 6. Example joint-forming tools (a) and the cross-section of a joint formed with the use of a round solid die (b): 1 – punch in a blank-holding sleeve with a spring; 2 – elastomer ring of the die with movable segments; 3 – blank-holding elastomer sleeve

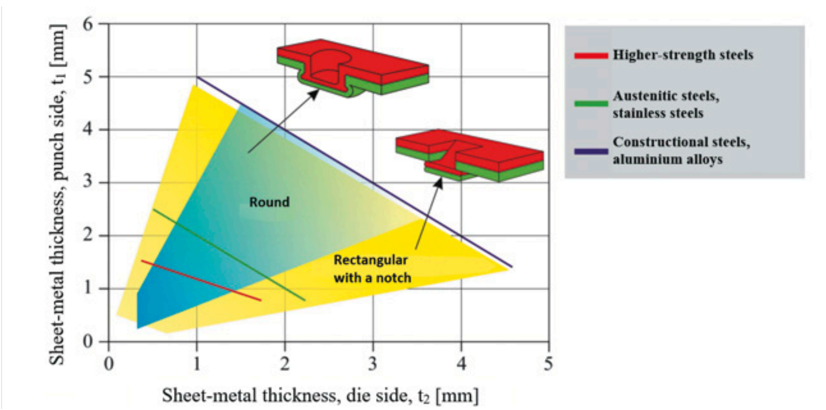

Fig. 7. Strength of the joints formed with the use of various tools

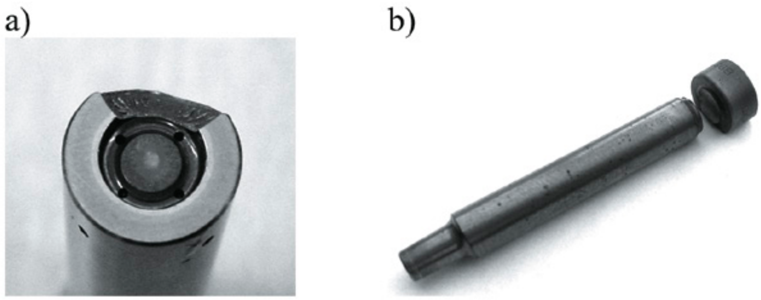

Fig. 8. Tools for the forming of a clinched joint, withdrawn from service: a) – die; b) – punch

It has already been for quite a long time that an industry's interest in new solutions in the field of assembly technology can be observed. This is particularly noticeable for the automotive industry. In response to a growing demand for lightweight structures of high strength, technologies of mechanical sheet metal joining under pressure have been comprehensively offered. One of them is the "clinching". The places where joints have been made by welding technologies (with the material having been melted) constitute potential sources of corrosion. On the other hand, clinching is less expensive in comparison with other classic material bonding methods: the clinching costs are lower by 35 % to even 65 % than those of spot welding [1, 13, 14]. The clinching compared with the classic bonding methods (fusion welding, pressure welding, classic riveting) has a number of good points, with the most important one being the absence of an additional fastener [15].

The clinching is an effective method of bonding the materials that have different mechanical properties, e.g. plastic materials with hard ones. This requires, however, careful approach to the selection of a system of material properties of the layers bonded together. The process parameters, especially the shape and geometry of the tools to be used, must be individually determined.

The use of clinched joints in the process of assembling vehicle body structures helps to save time and to eliminate additional actions related to the preparation of the parts for joining.

By increasing the pressing force and, thus, the thickness of the impression bottom, a higher strength of the joint may be obtained [16]. An assembly process that would comprise clinching operations should be designed to minimize the demand for the work to be done by the machine and to achieve maximum possible joint strength.

The CL technology is employed in automatized processes of assembling sheet metal structures. Automotive manufacturers more and more willingly use this solution, thus reducing the time and costs of product assembly processes. Its unquestionable advantages cause this method to be introduced to the mass production of motor vehicle bodies (Figs. 9 and 10).

Fig. 9. Assembly workstations where the clinching technology is used

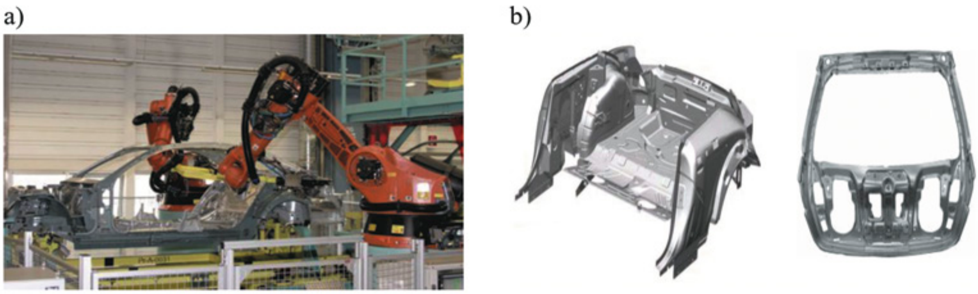

Fig. 10. Example of the assembly of Audi TT Coupé body components: a) – assembly workstation; b) – body components assembled with the use of the CL technology

In the European and US markets, there are a dozen or so large manufacturers of dedicated tools and equipment for automatic or manual joining. The solutions available in the market are offered in modular form, which facilitates the construction of workstations for the assembly of specific products. There is a wide range of systems driven electrically, pneumatically and hydraulically. The actuators used in the systems are often provided with sensors measuring the forming force and coupled with displacement sensors, which fundamentally facilitates the monitoring and controlling of the process. The designs of the workstations where the clinching technology is employed include both conventional and specialized machines. Their technological and engineering advancement level related to the automatization of delivering, positioning, and receiving of the product processed depends on the number of the parts being joined in a single operation and on the degree of complication of the product shape. In the case of processing motor vehicle bodies, the machines used are industrial robots combined with "C-frame" clinching equipment (Fig. 11). Such a solution is dictated by the necessity of adequate access to the points of joining.

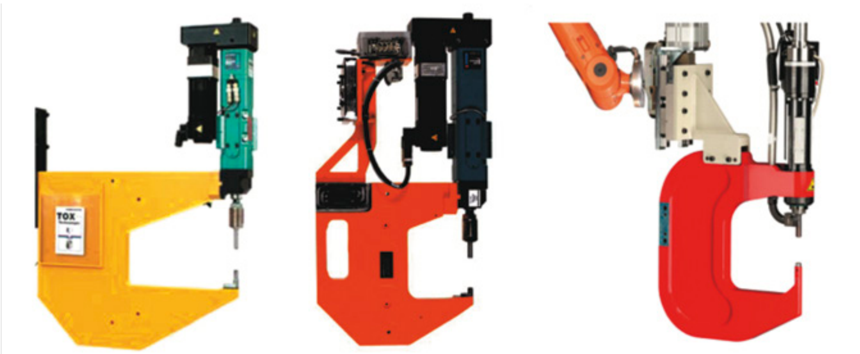

Fig. 11. Example designs of frames for industrial robots used for the assembly of motor vehicle bodies

Stationary presses may be adapted for the forming of clinched joints by providing them with additional dedicated jigs or multipurpose adapters and tools. Parts with more complicated shapes are joined together on specialized presses designed for being incorporated in production lines [17]. An example of the application of clinched joints for fixing a bracket of one of motor vehicle pedals has been presented in Fig. 12. It should be remembered that the cost of specialized workplaces rapidly increases with rising level of their automatization.

Fig. 12. Specialized machine for fixing a pedal bracket in a passenger car (a solution adopted by BTM Corporation)

In industrial conditions, the correctness of the joint-forming process is verified by monitoring the forming force curve (Fig. 13). In the case of an automatized process line, the process quality is continually checked by control programs.

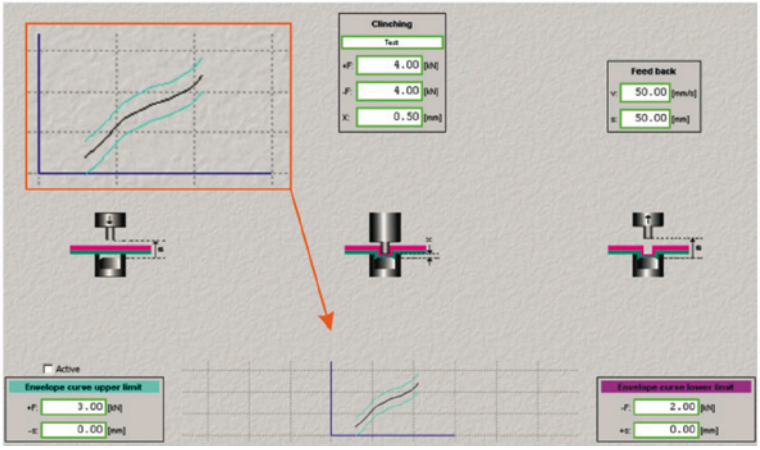

Fig. 13. Example window of a system to monitor the joint-forming force curve

The development of the material bonding technologies, including the clinching, means the launching of new engineering solutions aimed at increasing the joint strength. The objective remains unchanged: to reduce the costs of the existing material bonding technologies employed in the assembly processes. Any new modifications being introduced are to raise the strength of the clinched joints compared with those made to the existing solutions.

3. Clinching in automotive applications

The number of the leading motor vehicle manufacturers that employ the clinching technology is growing from year to year. The selected most interesting and relatively new automotive applications include:

- Audi (A3 – AU 353);
- Volkswagen (Polo – VW 240);
- Skoda (Roomster – SK 258);
- Jeep (Grand Cherokee);
- BMW (X5);
- Mercedes Benz (C-class);
- Porsche (911);
- Opel (Vectra);
- GMC (GMT 966);
- Buick (GMT 967);
- Saturn (GMT 968);

- Chevrolet (Epsilon – GMX 353);
- Pontiac (Grand AM);
- Shanghai GM (Cadillac CTS);
- Chrysler (Concord);
- Ford (Mustang);
- Nissan (Altima);
- Toyota (Lexus).

In consideration of their lower mechanical strength in comparison with that of round clinched joints, the rectangular clinched joints are used for preliminary bonding of vehicle body components before e.g. laser welding (Fig. 14).

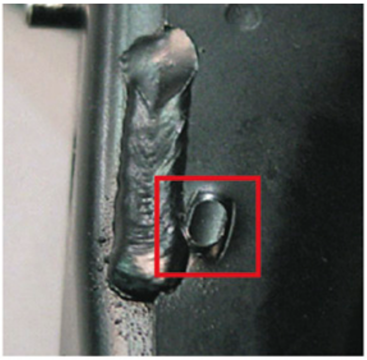

Fig. 14. Rectangular clinched joint used for the preliminary fixing of parts before their final bonding

The manufacturers of parts for the automotive industry increasingly often use this material-joining method. At present, many less critical structures are thus made, e.g. door window lifting linkage (Fig. 15).

a) b)

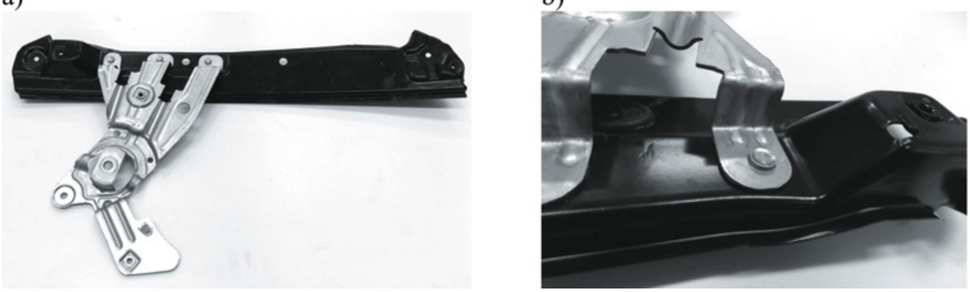

Fig. 15. Fragments of a door window lifting linkage: a) – supporting structure; b) – clinched joint, viewed facing the side formed by the die

The clinching is practiced in the automotive industry by both the final vehicle manufacturers and the component suppliers. The applications where the clinching is willingly used to bond sheet metal parts include the components where high strength of a joint is not required, e.g. exhaust system shields or brackets mounted in the vehicle undercarriage or engine compartment (Fig. 16) as well as parts made of aluminium alloys, which practically do not undergo corrosion and are characterized by low weight. In the case of fuel tank mounting straps, additional reinforcing elements are also used, with such elements being joined with the straps by e.g. clinching (Fig. 17).

Fig. 16. Protective shield to cover a part of a vehicle exhaust system

Fig. 17. Fuel tank mounting strap

The sheet metal components of vehicle bodies are chiefly formed by die shearing, bending, and press forming. For the sheared blank to be reinforced, it is often subjected to appropriate bending and/or press forming. Finally, the blanks are joined by clinching. The structure thus obtained (Fig. 18) is stiffened without any increase in its mass.

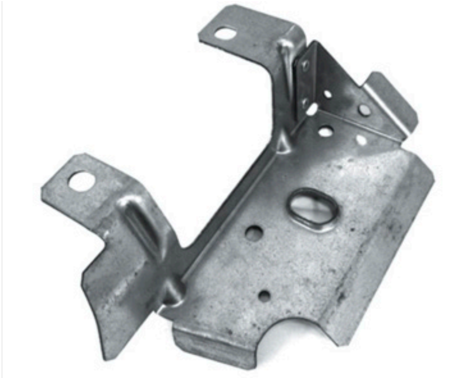

Fig. 18. A fastening portion of a bracket structure installed in the engine compartment

Windscreen wiper motor brackets, rear-view mirror housings, elements to fasten tanks of various kinds (Fig. 18) as well as structures of more critical importance, such as seat frames (Fig. 19) or components of the brake pedal supporting structure (Fig. 20) are only a few selected examples of the vehicle components where clinched joints are used.

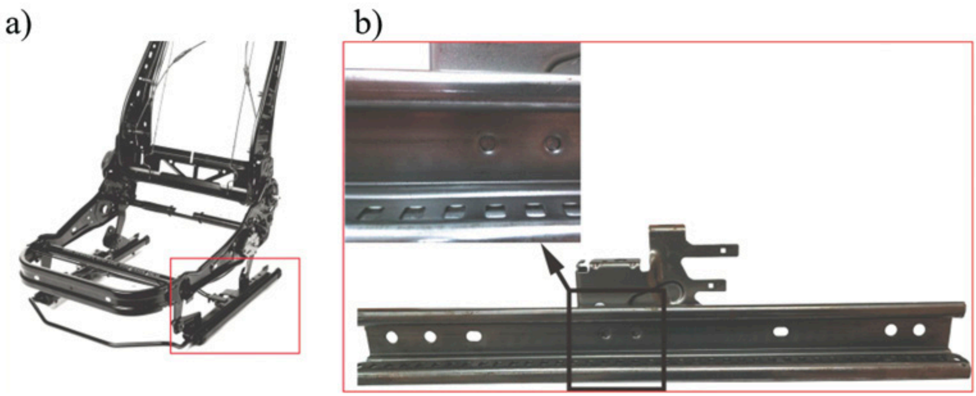

Fig. 19. Implementation of clinched joints in the construction of a vehicle seat: a) – seat frame; b) – seat sliding runner subassembly

Fig. 20. Brake pedal supporting structure

The clinching has already found application in the manufacturing of an extremely wide variety of thin-walled products, e.g. clutch shell made with the use of a system developed by TOX PRESSOTECHNIK (Fig. 21a) [18] or sunroof components (BTM system, Fig. 21b) [17]. In Volvo XC90, the sunroof (actually, its main supporting structure) comprises about 60 clinched joints. Another example may be the assembling of a car door structure from steel sheet and aluminium alloy components (Fig. 22). German manufacturers, e.g. Mercedes (Fig. 23), have been applying clinched joints since the end years of the last century.

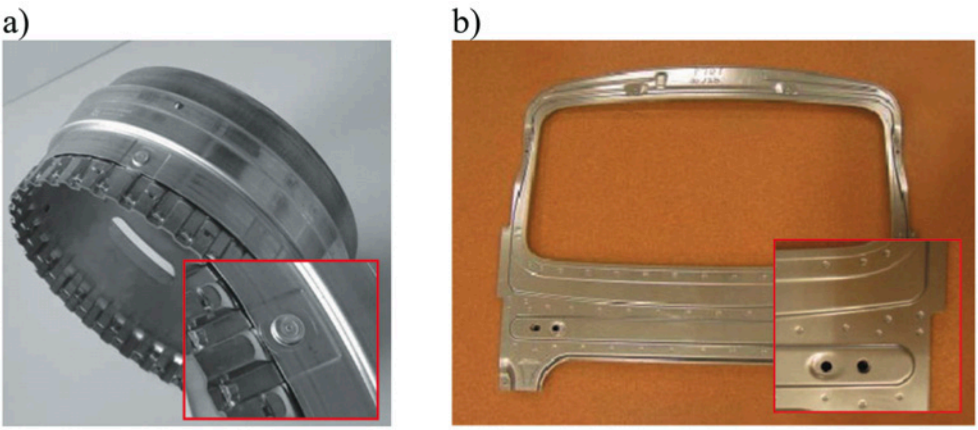

Fig. 21. Clinched joints: a) – in a clutch shell; b) – in a sunroof component

Fig. 22. Steel and aluminium door structure of a Honda motor vehicle

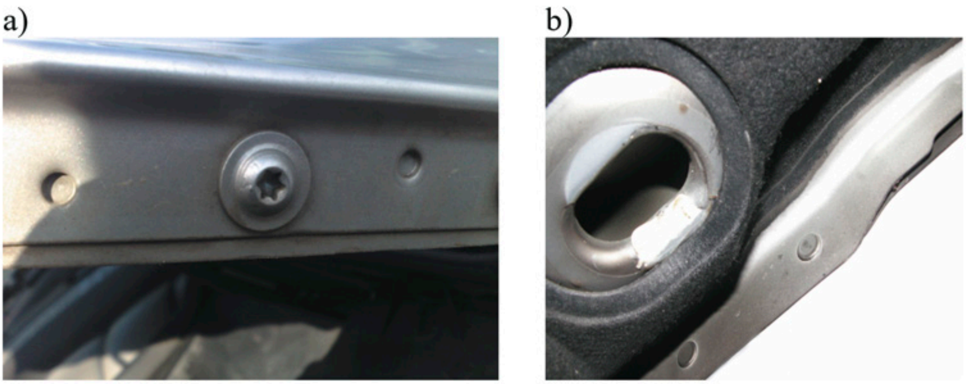

Fig. 23. Clinched joints in a Mercedes C-class: a) – fragment of the bonnet; b) – fragment of the boot lid

Fig. 24. New Fiat 500

A successful growth in the number of CL joints can be observed in new motor vehicles. Such joints have been introduced to vehicle assembly processes by Fiat Chrysler Automobiles in cooperation with TOX PRESSOTECHNIK. An example is the family of car bodies based on the Fiat 500 platform (Fig. 24). Another example may be the Audi A8 manufactured in Ingolstadt. The number of clinched joints in a car body has already exceeded 200.

4. Potential of clinched joints in the development of motor vehicle assembly technology

The clinching is a relatively old method of material bonding. The first idea of sheet metal joining by clinching was developed and the related patent application was submitted in Germany in 1897 [19]. Then, this method of material bonding sunk into oblivion for many years. Only as late as from 1980s on, high industry demand for the manufacturing of sheet metal products forced the preparation of adequately developed assembly systems.

In the production of thin-walled structures, classic joining techniques are used where drilling a hole is not required, e.g. pressure welding, rivet nut installation, or joining with the use of special screws. However, the special screws are an additional element indispensable for the joining operation; as regards the pressure welding, it conduces to the formation of corrosion centres with time at the weld points. The rivet nuts, in turn, considerably raise the mass of the sheet metal structure. At most of the classic assembly methods, a hole must be made in the parts involved before they are actually joined and this causes the assembly operation to be more expensive and complicated. However, such methods do not lead to troubles in the case of new high-strength materials being used for the production. High-strength steels are used for making vehicle components important for passive safety (Fig. 25), especially those constituting the crumple zones [20-23]. One of the directions where the potential of clinched joints may be utilized is the use of such joints in the parts intended to absorb the impact energy (Fig. 26).

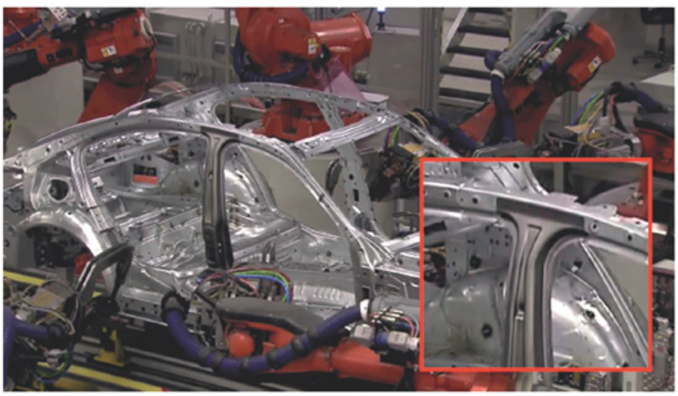

Fig. 25. The B-pillar, made of high-strength steel, of the BMW 3 car

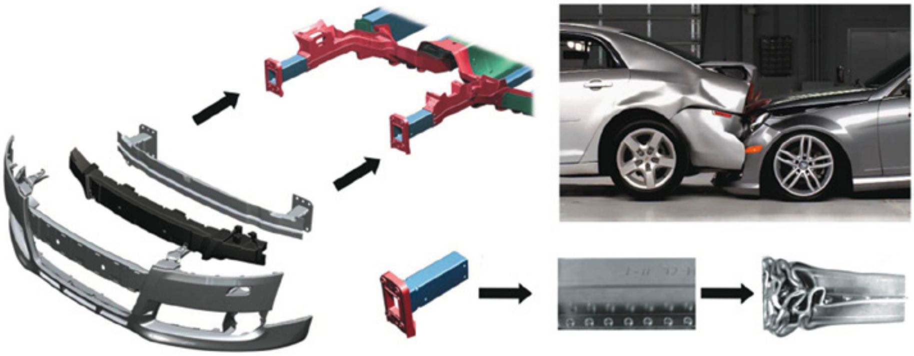

Fig. 26. Modelling and crash-testing of the vehicle body structures with clinched joints

At present, the mass percentage of plastics in the vehicle structure is 15-20 %, on the average [24]. The automotive industry and the cooperating research institutes in the world intensify their works related to the application of the material-joining method under consideration to plastics and composites (Fig. 27) [25-27]. As can be seen, the joining by clinching is an area for explorations intended to find new applications for such a technology.

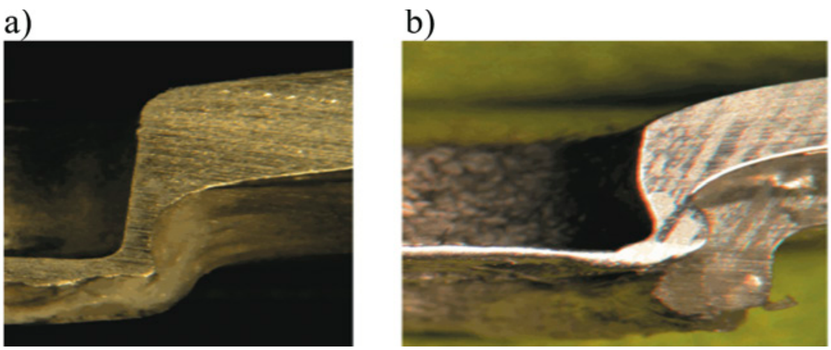

Fig. 27. Clinched joints of steel sheet with: a) – plastic; b) – carbon fibre composite

Glued joints are increasingly often used in motor vehicle assembly technologies. In the first constructions of the Volvo V70 models, such joints totalled about 1.5 m, while this figure has already grown to 35 m in the most recent models. The total length of glued joints is increasing with each vehicle model being launched. Joints based on adhesives used for the assembling of sheet metal structures have a considerable share in the products offered by various automotive vehicle manufacturers, as claimed in the advertising materials on the following motor cars:

- Volvo V70 (1.5 m);
- Mercedes E-class (45 m);
- Mercedes S-class (45 m);
- Audi A4 (50 m);
- BMW 5 (63 m);
- Mercedes CLK (71 m).

A solution that is very interesting and increasingly often applied is the making of hybrid joints [28, 29]. The hybrid joining of materials by gluing and clinching has gained in importance for the recent years (Fig. 29). Such a technology combines the good points of the clinched and glued joints.

Thanks to the use of joints of this kind:

- the stress concentration is reduced and thus the exertion of the structure as a whole is equalized;
- the strength of the structure and the absorption of the total destruction energy is raised;
- the structure is made stiffer;
- the air-tightness and resistance of the joint to corrosion is improved;
- the vibration-damping characteristics of the structure are improved.

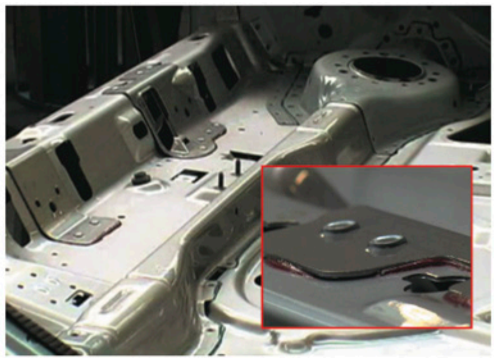

Fig. 28. Hybrid joint between sheet metal components of the Mercedes S-class body

It is difficult to determine the primacy of one of the constituent joint types over the other in a combined (hybrid) joint. Their roles depend on the pre-defined operational requirements. The clinched joint may serve as a stabilizer until the glue layer gains its full adhesive performance characteristics. Industrial glues have already become available that offer adhesive bonds of higher strength than the strength of the sheet metal material. However, they are not widely used because of their excessive cost. In addition to this, the glued joint is a sort of supplementation to a joint of another type. The adhesives and sealing compounds used at the bonding of motor vehicle body components improve the air-tightness of the structure and prevent moisture from penetrating the empty spaces between the material layers joined together.

The automotive applications discussed here are only a part of the present-day applications of modern assembly technologies [30].

5. Recapitulation

Increasingly stringent requirements related to the environmental protection and cost-effective manufacturing aspects determine the directions of development of vehicle bodies, in particular the constructions and technologies used in vehicle production. In spite of its drawbacks, the clinching technology is so interesting that it is developed towards the achieving of its best possible suitability for joining the components of new platforms of motor vehicle bodies.

In modern motor vehicle constructions, a growing share of clinched joints can be observed, especially as regards the joints being used in components of less critical importance. Such joints are also more and more frequently applied to the vehicle body parts that are important for passive safety. The spectrum of applications of the joints of this type has not run out yet; most likely, it will expand towards the joining of composites with steels or alloys based on aluminium and magnesium.

The clinched joints are so interesting from the point of view of the simplicity of the method how they are made that new modifications and applications of this technology may be expected.

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http://archiwummotoryzacji.pl.

References

[1] Mucha J (scientific editor). Badania i kierunki rozwoju technologii połączeń przetłaczanych na zimno (Research on cold clinching and directions of development of this technology). Oficyna Wydawnicza Politechniki Rzeszowskiej (Publishing House of the Rzeszów University of Technology), Rzeszów 2015, ISBN: 978-83-7934-020-0.

[2] Senkara J. Współczesne stale karoseryjne dla przemysłu motoryzacyjnego i wytyczne technologiczne ich zgrzewania (Contemporary car body steels for automotive industry and technological guidelines of their pressure welding). Przegląd Spawalnictwa, Vol. 81, No. 11 (2009), 3-7.

[3] Meschut G, Janzen V, Olfermann T. Innovative and highly productive joining technologies for multi-material lightweight car body structures. Journal of Materials Engineering and Performance, Vol. 23, No. 5 (2014), 1515-1523.

[4] Groche P, Wohletz S, Brenneis M, Pabst C, Resch F. Joining by forming – A review on joint mechanisms, applications and future trends. Journal of Materials Processing Technology, Vol. 214, No. 10 (2014), 1972-1994.

[5] Mori K-I. Joining processes by plastic deformation. Advanced Materials Research, Vols. 966-967 (2014), 29-47.

[6] Mori K, Bay N, Fratini L, Micari F, Tekkaya E. Joining by plastic deformation. CIRP Annals – Manufacturing Technology, Vol. 62 (2013), 673-694.

[7] Idzior M. Kierunki zmian materiałowych w motoryzacji w świetle wymogów ekologii (Directions of changes of materials in motorization in view of ecological requirements). MOTROL – Motoryzacja i Energetyka Rolnictwa, Vol. 9 (2007), 72-87.

[8] Alvesa L M, Diasb E J, Martinsa P A F. Joining sheet panels to thin-walled tubular profiles by tube end forming. Journal of Cleaner Production, Vol. 19, No. 6-7 (2011), 712-719.

[9] Ingarao G, Lorenzo R, Micari F. Sustainability issues in sheet metal forming processes: an overview. Journal of Cleaner Production, Vol. 19, No. 4 (2011), 337-347.

[10] Trendy w globalnej branży motoryzacyjnej i ich skutki dla Polski (Trends in the global automotive industry and their effects for Poland). Report of the KPMG International Cooperative (2013), 1-32.

[11] https://www.fraunhofer.de (02.10.2016).

[12] Mucha J. The analysis of rectangular clinching joint in the shearing test. Eksploatacja i Niezawodnosc – Maintenance and Reliability, Vol. 51, No. 3 (2011), 45-50.

[13] Mucha J, Kaščák L, Spišák E. Analiza wytrzymałości złączy przetłoczeniowych blach stalowych, stosowanych na elementy nadwozi pojazdów samochodowych (The strength analysis of steel sheet clinching joints used in motor-car body elements). Archiwum Motoryzacji, No. 3 (2010), 185-194.

[14] Kaczyński P, Rusiński E. Ocena wytrzymałości połączeń punktowych w cienkościennych strukturach energochłonnych (Evaluation of the strength of spot joints in thin-walled energy-absorbing structures). Oficyna Wydawnicza Politechniki Wrocławskiej (Publishing House of the Wrocław University of Science and Technology), Wrocław 2014.

[15] Mucha J. Rozwój technik wytwarzania złączy nitowych – nitowanie bezotworowe (History of the riveted joint technique (Self Piercing Riveting – SPR)). Mechanik, No. 5-6 (2007), 454-454.

[16] Mucha J. The analysis of lock forming mechanism in the clinching joint. Materials and Design, No. 32 (2011), 4943-4954.

[17] http://www.btmcorp.com (visited on 2 Feb. 2015).

[18] http://www.tox-pl.com (visited on 1 Jan. 2015).

[19] Deutsches Reichspatent, DRP-Nr. 97517, (1897).

[20] Bartczak B, Gierczycka-Zbrożek D, Gronostajski Z, Polak S, Tobota A. The use of thin-walled sections for energy absorbing components: A review. Archives of Civil and Mechanical Engineering, 10(2010)4, 5-19.

[21] Gronostajski Z, Polak S. The application of clinching techniques to join impact energy absorbing thin-walled aluminium sections. Archives of Metallurgy and Materials, Vol. 54, No. 3 (2009), 695-703.

[22] Gronostajski Z, Bandoła P, Karbowski P. The effect of crashworthiness parameters on the behaviour of car-body elements. Archives of Civil and Mechanical Engineering, Vol. 6, No. 1 (2006), 31-46.

[23] Kaczyński P. Kryterium doboru własności wytrzymałościowych połączeń profili cienkościennych obciążonych udarowo (A criterion of the selection of strength properties of joints in thin-walled profiles subjected to impact loads). In: Szrek J. (ed.), Interdyscyplinarność badań naukowych (Interdisciplinarity of scientific research), Oficyna Wydawnicza Politechniki Wrocławskiej (Publishing House of the Wrocław University of Science and Technology), Wrocław 2009, 117-120.

[24] Bielefeldt K, Papacz W, Walkowiak J. Ekologiczny samochód. Tworzywa sztuczne w technice motoryzacyjnej, cz. 1 (Environmentally friendly car. Plastics in automotive engineering, Part 1). The Archives of Automotive Engineering (Archiwum Motoryzacji), Vol. 52, No. 2 (2011), 117-131.

[25] Lambiase F, Di Ilio A. Mechanical clinching of metal-polymer joints. Journal of Materials Processing Technology, No. 215 (2015), 12-19.

[26] Lambiase F, Di Ilio A, Paoletti A. Joining aluminium alloys with reduced ductility by mechanical clinching. International Journal of Advanced Manufacturing Technology, Vol. 77, No. 5-8 (2015), 1295-1304.

[27] Lambiase F. Joinability of different thermoplastic polymers with aluminium AA6082 sheets by mechanical clinching. International Journal of Advanced Manufacturing Technology, DOI 10.1007/s00170-015-7192-1.

[28] Balawender T, Sadowski T, Golewski P. Experimental and numerical analyses of clinched and adhesively bonded hybrid joints. Journal of Adhesion Science and Technology, Vol. 25, No. 11 (2011), 2391-2407.

[29] He X, Zhao L, Yang H, Xing B, Wang Y, Deng C, Gu F, Ball A. Investigations of strength and energy absorption of clinched joints. Computational Materials Science, Vol. 94, No. 1 (2014), 58-65.

[30] Kaščák L, Mucha J, Slota J, Spišák E. Application of modern joining methods in car production. Oficyna Wydawnicza Politechniki Rzeszowskiej (Publishing House of the Rzeszów University of Technology), Rzeszów 2013, ISBN: 978-83-7199-903-8.