UDC 629.735.33.023
N.Nechiporuk [1], Yu.Vorobyov [1], V. Voronko [1], N.Skalyga [2]
[1] National Aerospace University "Kharkiv Aviation Institute"
[2] Lutsk National Technical University

DEFECTS RESEARCH OF THE TITANIUM RIVETS BUCKED HEADS

The results of macrostructure metallographic analysis of the bucked heads cracking of BT16 (Ti-3Al-4.5V-5.0Mo) alloy that realized in a variety of riveting ways.

Key words*: rivet, bucked head, press riveting, pulse riveting, macrosection, metallographic examination.*

Problem definition

The weight minimization, increases in rigidity, in strength, in service life and in reliability are considered as the most important requirements to the modern aircraft design. Using structural components made of polymeric composite material first of all may satisfy such complex of requirements.

Carbon fibres are the most perspective as reinforcing material for polymeric matrices strengthening due to high specific strength and rigidity.

At the same time the main condition for further spreading of using of polymeric composite materials is application of effective methods of joining.

The main advantages of impulse riveting are follows:

- High stability of joint parameters.
- Radial interference can be controlled along thickness by forming speed and conditions.
- Increased static and fatigue strength, joint tightness.
- No delamination.
- Joint quality non-dependant on working force skills.
- Less noise and vibration.
- Appropriate hand tool can be created.

To ensure joint strength during heating and under the influence of the electrochemical corrosion it is necessary to use rivets made of corrosion-resistance materials (corrosion-resistant steels, titanium alloys). But it complicates the problem of minimizing of the stress and strain during composite structural elements riveting.

In view of mentioned above selection of the rational regime and tooling for impulse riveting of aircraft composite structural elements is extremely actual problem.

Research aim and tasks to perform

The main technological problem of the article is rational choice of the parameters of impulse riveting of aircraft carbon composite structural elements with high strength titanium rivets based upon the following requirement:

(1) Quality maintenance.
(2) Increase of static strength.
(3) Increase of riveted joints durability.

It is assumed, that the quantity and the distribution of radial interference in joint as generally recognized criterion of strength, durability and air-tightness may be approved as a factor governing quality of the riveted joints [1-6 and others]. In this article handle a problem of cracking of the bucking heads of the rivets.

Research results

On the base of scientific and technical literature, preliminary conducted tests and experience the followings criteria were approved as the factors governing quality index of riveted joints of composite with titanium rivets with washes of BT16 (Ti-3Al-4.5V-5.0Mo) alloy:

(1) Method of riveting (press or impulse).
(2) Speed of deformation ϑ_{def} (work A_{def} or energy of deformation E_{def}).
(3) Parameters of deformation (geometry of the working elements of a riveting set:

R_{sphere} and h_{sphere} (Fig. 1); geometry of a bucking bar – flat surface of working element or with impression shape of which corresponds to the shape of the manufactured head.

(4) Geometry of a washer (diameter of the hole d_{hole}^{washer}, chamfer dimension from the side of bucking head $D_{chamfer}$ and $h_{chamfer}$).

(5) Thickness of the stack of the joined parts S and hole diameter for rivet d_{hole}.

Press and impulse methods of riveting are chosen with accordance with project specification. Press riveting is done on the riveting press of КП-204M series and impulse with air-impact (pneumoimpulsive) riveting hammer of МПИ-90M series.

The speed of press riveting is not too large ϑ_{def}^{press} =5·10^{-3} m/s and is a constant during all process of deformation. Impulse riveting is carried out depending on condition of upsetting of rivet with initial speed of deformation $\vartheta_{def.\,0}$ =25…30 m/s (or E_{def} =44…63 joule). Required for riveting energy of deformation E_{def} and therefore the speed $\vartheta_{def.\,0}$ will depend on conditions of deformation.

Conditions of deformations depend on the shape and dimension of working elements of a riveting set, bucking bar and upsetting speed. Impulse riveting is carried out with flat riveting sets and with riveting sets with spherical impression with $R_{impression} = 1.5\,d$, $h_{impression} = 0.25\,d$ (dimensions of the spherical impression are selected on the base of preliminary tests results). Using of the spherical impression allows to increase interference in joint and to reduce concentration of the plastic deformation in bucking head of rivet (to smooth upper boundary of the cone of the slip).

For the purpose of reduction of knockout and of deformation of the manufactured head it is common practice to use bucking bar with impression shaped according this head. However there is increase of nonuniformity of the interference throughout the thickness of the parts in this case. The "bucking bar – manufactured head" contact area $F_{bucking\ bar}$ is approved as a numerical parameter. There is a contact on the end face of manufactured head when using flat bucking bar and $F_{bucking\ bar}^{flat}$ =24.6 mm^2, and when using bucking bar with rivet head-shaped impression $F_{bucking\ bar}^{primary}$ =87 мм^2. According previous investigation [4] the mass of bucking bar for impulse riveting doesn't influence magnitude and distribution of radial interference (Fig. 2).

During the test it was determined that chipping of the bucked heads occurs only in case of one dimension-type of the rivets according 4-12 OCT 1.34008-86 during riveting with a riveting set with a flat working zone and with a washer without modification. The percentage of defective rivets was equal to 12.3% of the total amount of the used rivets. For production lot of the rivet of 4-10 dimension-type there were no chip of the bucking heads. At the same time degree of upsetting of the rivet shank doesn't exceed limiting value prescribed by branch norms $\varepsilon =$ 0.54…0.66 [6-9].

Cracking of the bucked heads may occur due to low quality of the wire and of the rivets (for example the control scrapping of the rivet made of alloy of B65 series during manufacturing may reach 25…30% [10]) and due to localization of the plastic deformation.

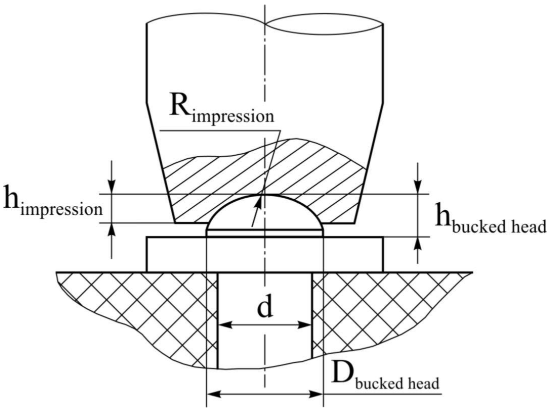


Fig. 1 – Dimension of the spherical impression in riveting set

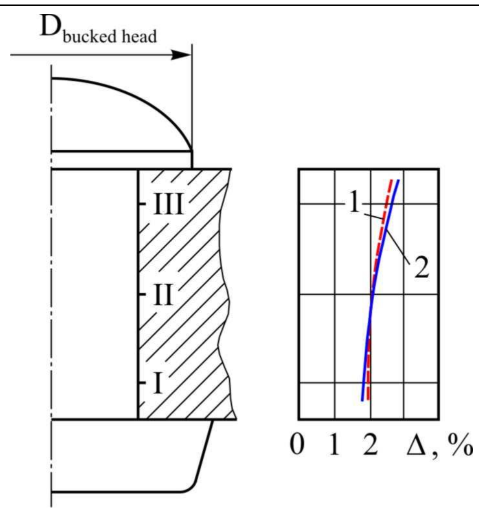


Fig. 2 – Influence of the bucking bar mass on distribution of the radial interference in riveted joints produced by impulse riveting with ЗП-4-9 rivets: 1 – $m_{bucking\ bar} = 0.7\ kg$; 2 – $m_{bucking\ bar} = 25\ kg$

Component analysis of the rivet material of the different lots made by scanning electron microscope of РЭМ-106 series shows that material composition of the rivet lot of the dimension-type 4-10 OCT 1.34008-86 slightly differs from the composition of other rivet (Fig. 3) and from the composition approved according to OCT 1.34008-86. It is assumed, the plasticity of the alloy is reduced due to violation of the rivet manufacturing technique (violation of annealing procedure and of heading of the manufacturing head). The increased vanadium percentage V, decreased aluminium percentage Al, and cuprum occurrence Cu may cause creation of the mechanically non-stable β-phase which undergoes martensitic transformation $\beta \rightarrow \alpha''$ that leads in its turn to decreasing of plasticity.

The use of modificated alloy of BT16 series (Ti-3.2Al-4.4V-5.1Mo) as material for titanium rivets may help to eliminate revealed defect. Such alloy has ultimate strain during compression $\varepsilon = 0.76$ and increased ultimate tensile strength $\sigma_в = 1055$ MPa [10].

Preliminary impulse riveting tests reveal high sensitivity of the alloy of BT16 series to the deformation velocity ϑ_{def} and to the degree of upsetting ε. For the purpose of finding remedy to avoid bucked heads cracking the samples of riveted joints made by press and by impulse riveting were subjected to macroscopic metallographic investigations (Fig. 4).

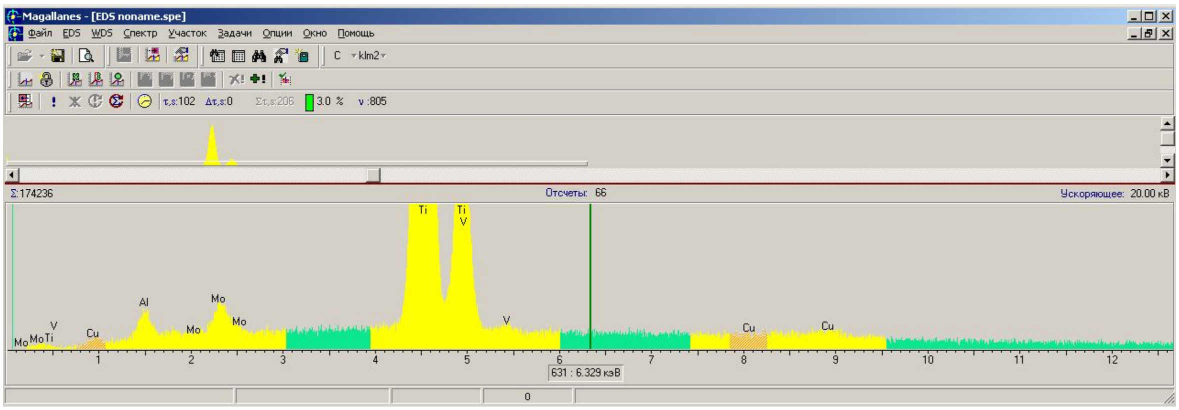
As one can see at macrosections during press riveting (deformation velocity $\vartheta_{def} \cong 5\times10^{-3}$ m/s, degree of upsetting ε=0.58) there is no localisation of the plastic deformation through all cross-section of the rivet (Fig. 4, a).

Impulse riveting was carried out with initial deformation velocities 25 and 30 m/s and with degree of upsetting of the bucking head 0.60 and 0.52 in case of flat riveting set and riveting set with spherical impression $R_{impression} = 1.5d$ respectively. There was localisation of the plastic deformation in bucking head in both cases, but their nature and degree were different.

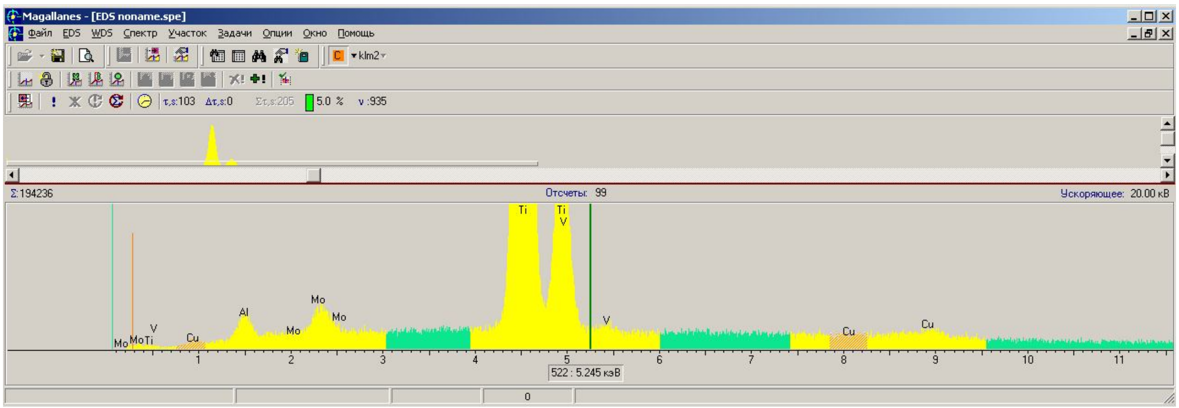
During impulse riveting with a flat riveting set (Fig. 4, b) the cones of the slip were observed. They divide the dead zone in the upper part of the bucking head and the rivet shank where the lateral deformation zones were formed. There were cracks on the boundary. The slip cones diverged in lateral direction due to high degree of upsetting of the bucking head.

The use of the riveting set with spherical impression $R_{impression} = 1.5d$ (Fig. 4, c) allows to smooth the upper boundary of the slip cone. Disruption of continuity were observed only in the transition zone between shank and bucking head of the rivet.

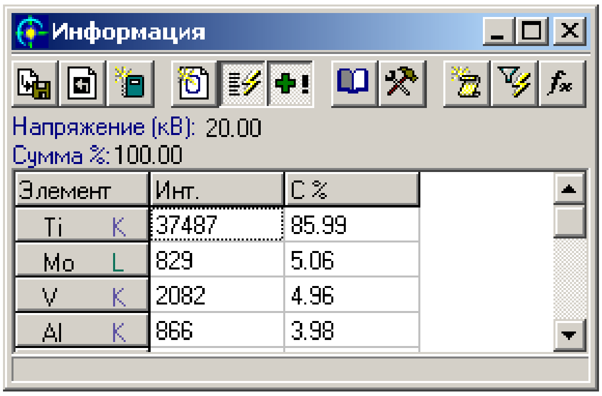
The use of the bucking bar with an impression shaped according manufactured head of the rivet doesn't influence on the flow of the material of the rivet (Fig. 4, d) but allows to reduce deformation in the manufactured head.



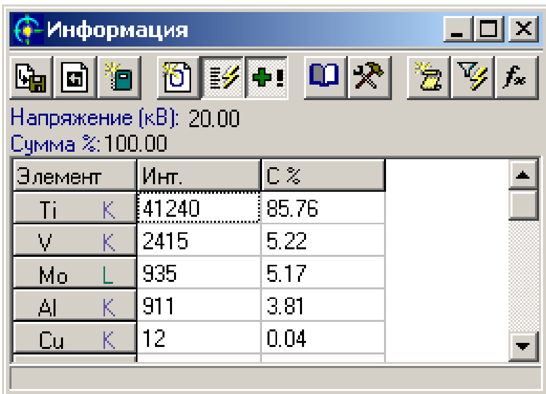
a



b



c



d

Fig. 3. The results of component analysis of the material of the titanium rivets:
a, **c** – the general spectrum and components percentage of the rivets of the 4-10 OCT 1.34008-86 dimension-type lot; **b**, **d** – the general spectrum and components percentage of the rivets of the 4-12 OCT 1.34008-86 dimension-type lot

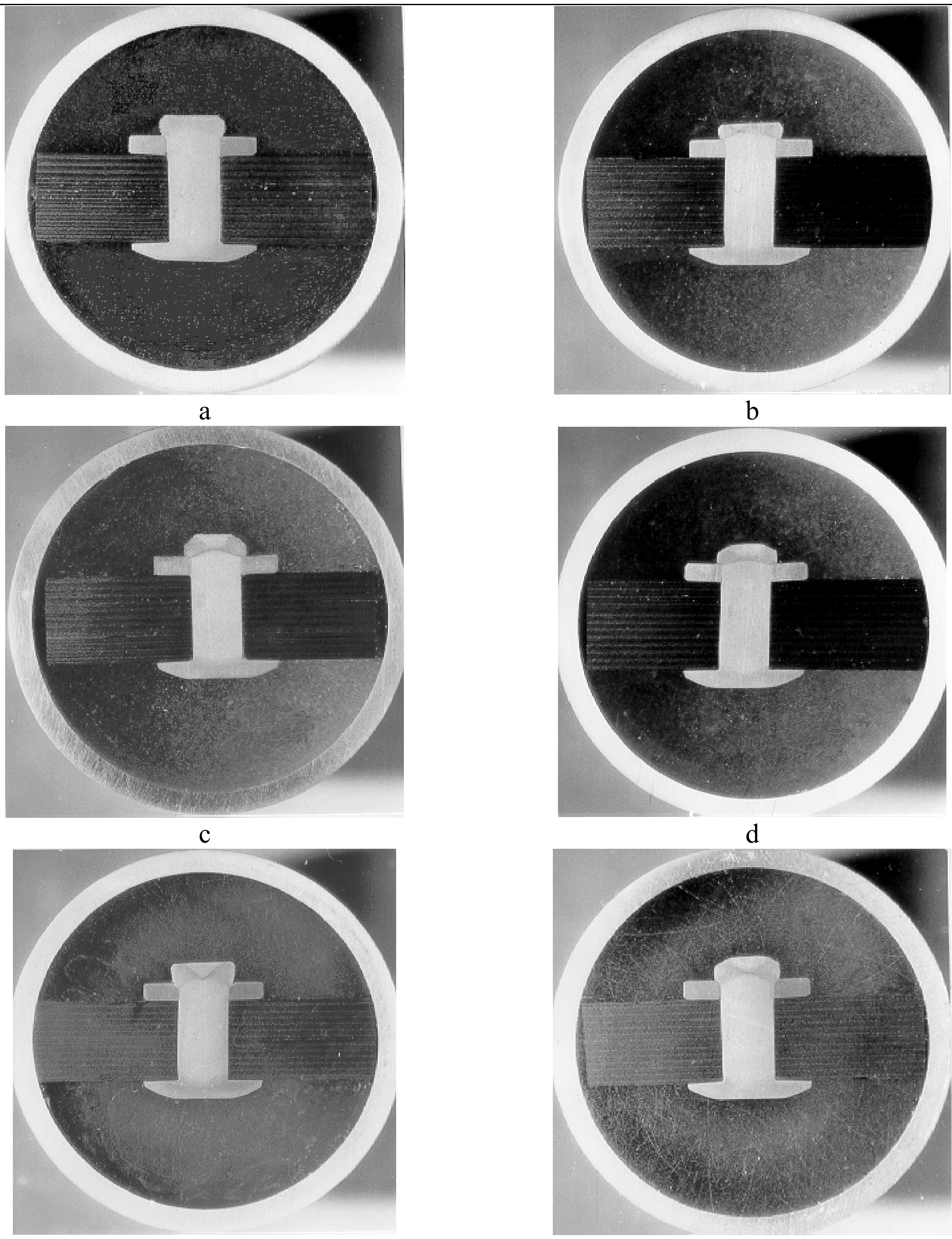


Fig. 4. The macrosections of the joints produced by press (**a**) and impulse (**b**) riveting (**b - f**): **b** – the riveting set and the bucking bar with a flat working zone; the washer without modification; **c, d** – the riveting set with a spherical impression, the bucking bar with a flat working zone and with an impression shaped according manufactured head of the rivet respectively; the washers without modification; **e, f** – the riveting set with a flat working zone and with spherical impression respectively; the bucking bar with a flat working zone; modificated washer with increased chamfer 0.5×90°

Modification of the washer facilitates increasing of the magnitude of the radial interference in the joint. At the same time it doesn't manifest itself essentially in uniformity of radial interference through the thickness of the stack.

The dead zone with boundary of cracking in the upper part of the bucking head mustn't influence on riveted joint strength during riveting with flat riveting set (Fig. 4, e). Combination of the semispherical shape of the bucking head with increased chamfer at washer improves the flow of material of the rivet (Fig. 4, f) and excludes cracking.

Conclusions

During press riveting there is no localisation of the plastic deformation through all cross-section of the rivet. Contrariwise during impulse riveting was localisation of the plastic deformation in bucking head in both cases, but their nature and degree were different.

During impulse riveting with a flat riveting set the cones of the slip were observed. They divide the dead zone in the upper part of the bucking head and the rivet shank where the lateral deformation zones were formed. There were cracks on the boundary. The use of the riveting set with spherical impression $R_{impression} = 1.5d$ allows to smooth the upper boundary of the slip cone. Disruption of continuity were observed only in the transition zone between shank and bucking head of the rivet.

The dead zone with boundary of cracking in the upper part of the bucking head mustn’t influence on riveted joint strength during riveting with flat riveting set. Combination of the semispherical shape of the bucking head with increased chamfer at washer improves the flow of material of the rivet and excludes cracking.

1. Технология самолетостроения: Учебник для авиационных вузов. / А.Л. Абибов, Н.М. Бирюков, В.В. Бойцов и др. Под ред. А.Л. Абибова. – 2-е изд. перераб. и доп. – М.: Машиностроение, 1982. – 551 с.
2. Технология выполнения высокоресурсных заклепочных и болтовых соединений в конструкциях самолетов. / А.И. Ярковец, О.С. Сироткин, В.А. Фирсов, Н.М. Киселев. – М.: Машиностроение, 1987. – 192 с.
3. Лепетюха В.С. Исследование, разработка и внедрение технологии клепки импульсными пневмогидравлическими молотками при сборке самолетных конструкций. Дис…канд. техн. наук. – Харьков, ХАИ, 1976. – 176 с.
4. Чистяк В.Г. Исследование процесса, разработка и внедрение технологии пневмоимпульсной клепки самолетных конструкций высокоресурсными заклепками. Дис…канд. техн. наук. – Харьков, ХАИ, 1986. – 163 с.
5. Воробьев Ю.А. Разработка технологического процесса и инструмента импульсной клепки авиационных конструкций из углепластика: Дис…канд. техн. наук: 05.07.04. – Х., 2004. – 166 с.
6. Вигдорчик С.А. Конструктивно-технологические пути увеличения усталостного ресурса самолетов. М.: МАИ. 1980. – 64 с.
7. Выполнение соединений титановыми заклепками с шайбой в пакетах, содержащих КМ: ТИ 36-43-90: Утв. НИАТ 01.09.89: Срок действия установлен с 01.01.90 / АНТК им. О.К. Антонова. – К., 1989. – 36 с.
8. Выполнение высокоресурсных заклепочных соединений в углепластиках заклепками из титанового сплава: ТР 4115.10-86: Утв. НИАТ 01.09.86: Срок действия установлен с 01.09.86 / НИАТ. – М., 1986. – 23 с.
9. ОСТ 1 34008-86. Заклепки с плоско-скругленной головкой из титанового сплава. Конструкция и размеры. – Введ. 01.01.87. – М.: Изд-во НИИАТ, 1987. – 5 с.
10. Громов В.Ф., Строгова И.Б. Выполнение заклепочного соединения из модифицированного сплава В65 // Тезисы докладов отраслевого научно-технического семинара «Совершенствование процессов выполнения высокоресурсных заклепочных соединений в конструкциях из легких, жаропрочных сплавов и композиционных материалов». Самара, 15-17 октября 1991. – С. 15-16.
11. Ильин А.А., Скворцова С.В., Овчинников А.В., Ручина Н.В Влияние структуры сплава ВТ16 на его технологическую пластичность. // Авиационная промышленность. – 2006. – №3. – С. 43–49.