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Razvoj žaroobstojnih aluminijevih zlitin

Development of heat resistant aluminium alloys

Povzetek

Proizvodnja aluminijevih zlitin narašča zaradi njihove majhne gostote ter velikega specifičnega modula in trdnosti. Te lastnosti lahko bistveno zmanjšajo emisije CO_2 in porabo energije v transportu ter gradbeništvu. Konvencionalne aluminijeve zlitine imajo sorazmerno majhno toplotno obstojnost, saj izgubijo večji del svoje trdnosti, če jih segrejemo nad 250 °C. V zadnjih letih so se povečale zahteve po žaroobstojnih aluminijevih zlitinah, zato so v zadnjih letih raziskovali in razvili več novih zlitin. Pri številnih pristopih so bile uporabljene nove tehnologije, kot sta litje na vrteče se kolo (melt-spinning) in ekstruzija trakov pri izdelavi Scalmalloy®, plinska atomizacija and sintranje pri izdelavi nanokvazikristalnih zlitin ter izdelava z dodajalnimi tehnologijami (npr. s selektivnim laserskim taljenjem). Raziskovali so tudi številne aluminijeve livarske zlitine, kot sta Al-Si in Al-Cu-Si, kakor tudi gnetne zlitine. Toplotna obstojnost aluminijevih zlitin se poveča z nastankom temperaturno obstojnih faz, ki lahko nastanejo pri strjevanju kot tudi pri toplotni obdelavi. V predstavitvi bo podan pregled različnih pristopov, v središču pa bodo aluminijeve livarske zlitine.

Ključne besede: aluminij, toplotna obstojnost, trdnost, lezenje

Summary

The production of Al-alloys strongly increases due to their low density, high specific modulus and strength. These properties can significantly reduce CO_2 emissions and energy consumption in transportation and construction. The conventional Al-alloys possess rather low heat resistance as loose very rapidly their strength when heated above 250 °C. The demands for the high heat-resistant Al-alloys have been increased recently. Therefore, several new alloys have been investigated and developed over the last years. The most important approaches are through the application of modern technologies; such as melt-spinning and extrusion of ribbons by the development of Al-Mg-Sc-Zr alloys, gas atomisation and sintering of nanoquasicrystalline strengthened alloys and additive technologies (selective laser melting). There are several investigations regarding heat resistance of casting alloys, such as Al-Si and Al-Cu-Si, and wrought alloys. The heat resistance is improved by the formation of the temperature resistant phases, which can be formed during solidification or heat treatment. In the article different approaches will be presented, with the focus on the casting alloys.

Key words: aluminium, heat resistance, strength, creep

Definicije pomembnih pojmov [1]

Visokotemperaturne lastnosti

Visokotemperaturne lastnosti so lastnosti, ki jih imajo materiali pri povišanih

Definition of important terms [1]

High-temperature properties

Properties were tested at higher temperature, depending on the soaking temperaturah. Odvisne so od časa zadrževanja pri povišanih temperaturah. Na napetost tečenja in natezno trdnost močno vpliva tudi hitrost deformacije.

Rekuperacija

Rekuperacija je povezana s primerjavo lastnosti po izpostavitvi povišani temperaturi in lastnostmi pred izpostavitvijo. Preizkuse navadno izvajamo pri sobni temperaturi.

Regresija

Regresija se pogosto pojavi v toplotno obdelovalnih zlitinah, kadar je temperatura uporabe višja od temperature staranja. Izpostavitev višji temperaturi v začetku povzroči raztapljanje izločkov, ki so nastali pri staranju, kar sčasoma vodi do zmanjšanja lastnosti pri povišani temperaturi in pri rekuperaciji. Kasneje se pojavi ponovno izločanje pri temperaturi testiranje in povzroči rekuperacijo trdnosti.

Lezenje

Lezenje je rezultat številnih mikroplastičnih procesov, ki potekajo v sorazmerno dolgih časovnih obdobjih. Obremenitve ob hkratni izpostavljenost povišanim temperaturam povzročajo trajno deformacijo v smeri delujoče napetosti. Pri hujših obremenitvah se poškodbe akumulirajo in privedejo do loma.

Temperaturna odvisnost napetosti tečenja

Slika 1 prikazuje značilno spreminjanje napetosti tečenja aluminijevih zlitin s temperaturo [2]. Visokotemperaturna trdnost se močno zmanjša pri temperaturah nad 250 °C. Pri okoli 300 °C znaša visokotemperaturna napetost tečenja le 0,15−0,40 trdnosti pri sobni temperaturi. Napetost tečenja pri 500 °C je manjša kot 5 % napetosti tečenja pri sobni temperaturi. To jasno kaže, da aluminijeve zlitine

time at this temperature. Also, the strain rate during testing has a very strong effect on the values of yield and ultimate strengths.

Recovery properties

Recovery properties relate to the effect of exposure at any temperature on the property characteristics, compared with those achieved before the exposure. Testing is normally performed at room temperature.

Regression or reversion

Regression or reversion is often observed in heat treatable alloys when the application temperature is higher than the aging temperature. Exposure initially results in resolution of precipitates characteristic of the aging temperature, leading to a significant decrease in both recovery and elevated temperature strength. This is followed by a second precipitation, characteristic of the exposure temperature and leading to a partial recovery in strength.

Creep

Creep is a manifestation of the accumulation of many microplastic events occurring over a nominally long period of time. The application of stress at the exposure temperature leads to a permanent strain in the direction of the applied stress. Under severe conditions, this leads to significant damage accumulation and finally rupture.

Temperature dependence of the yield strength

Figure 1 shows typical variation of the yield strength of aluminium alloys with temperature [2]. The elevated-temperature strength drops to strongly above 250 °C. At about 300 °C, the elevated yield strength is from 0.15-0.40 of the room temperature strength. The yield strength at 500 °C is less than 5% of the room temperature yields hitro izgubljajo trdnost pri segrevanju na povišane temperature.

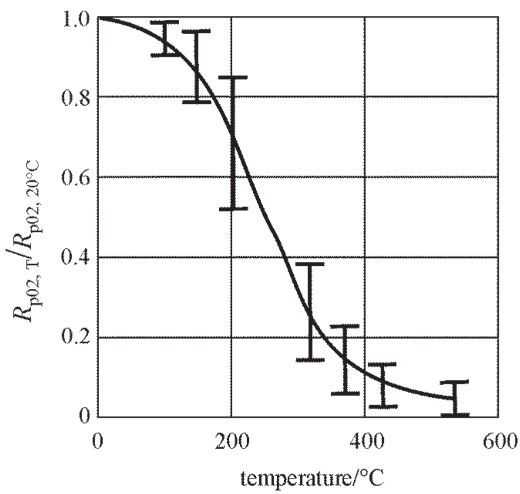


Figure 1. Spreminjanje napetosti tečenja aluminijevih zlitin s temperaturo [2]

Figure 1. Variation of the yield strength with temperature of aluminium alloys [2]

Zlitina 2618 Hiduminium RR 58

Zlitina 2618 je temeljna primerjalna zlitina za uporabo pri povišanih temperaturah. Slika 2 kaže njene značilne lastnosti pri teh temperaturah. Njena kemijska sestava v masnih deležih je 0.18% Si; 2.30% Cu, 1,60% Mg, 1,1% Fe, 1,0% Ni and 0,07% Ti [3]. V stanju T6 je utrjena z izločki S' (Al_2CuMg).

Pri izpostavitvi povišanim temperaturah začne ob enourni izpostavitvi izgubljati trdnost nad 175 °C, medtem ko začne trdnost pojemati že pri temperaturah nad 100 °C, ko je zlitina izpostavljena povišani temperaturi 1000 h (Fig. 2).

Desni diagram na Fig. 2 prikazuje spreminjanje napetosti tečenja po izpostavitvi temperaturam 200 °C in 250 °C v odvisnosti od časa izpostavitve, pri čemer se močnejše zmanjšanje napetosti pojavi strength. This clearly shows that typical aluminium alloys rapidly lose their strength when heated to higher temperatures.

Alloy 2618 Hiduminium RR 58

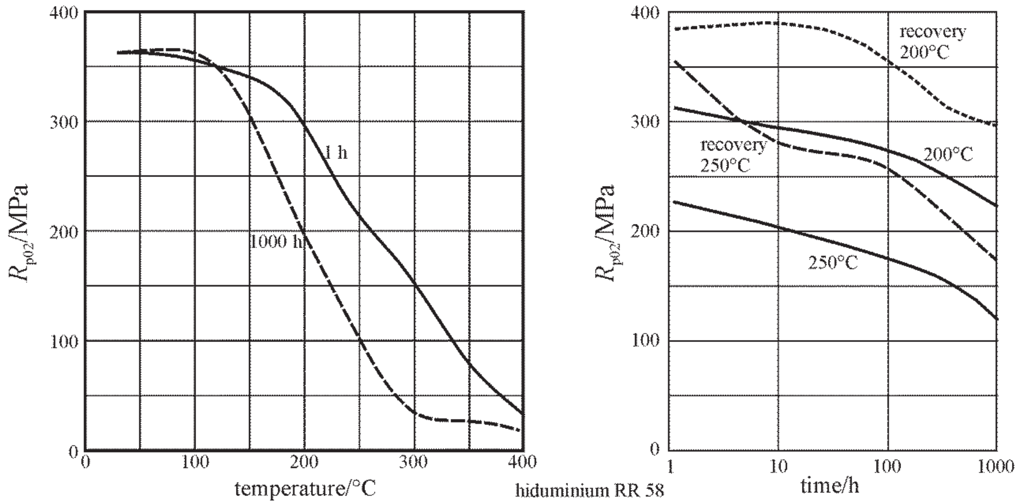
The alloy 2618 presents a benchmark for Al-alloys used at elevated temperatures. Figure 2 shows typical high temperature properties. The chemical composition in wt.% is 0.18% Si; 2.30% Cu, 1.60% Mg, 1.1% Fe, 1.0% Ni and 0.07% Ti [3]. In the T6 condition, the alloy has S' (Al_2CuMg) precipitates.

When the alloy is exposed to an elevated temperature for 1 h, the strength starts to drop rapidly above 175 °C, while the strength drops rapidly at temperatures as low as 100 °C, when the alloy is exposed to this temperature for 1000 h (Fig. 2).

The right diagram in Fig. 2 shows the variation of yield strength after exposure to 200 °C and 250 °C, where stronger reduction of properties occur at exposure longer than 100 h. Fig. 3 shows typical creep curves.

Casting alloys

Nasa developed a series of Al-Si alloys having improved mechanical properties at elevated temperatures. The patented composition of the alloy in the weight percentages is: 6.0-25.0 % Si, 5.0-8.0%Cu, 0.05-1.2% Fe, 0.5-1.5 %Mg, 0.05-0.9%Ni, 0.05-1.2 % Mn, 0.05-1.2% Ti, 0.05-1.2%Zr, 0.05-1.2%V, 0.05-0.9 %Zn, 0.001-0.1 % Sr, 0.001-0.1 % P, and the balance is aluminium [4]. The aluminium alloy contains a simultaneous dispersion of three types of Al_3X compound precipitates (X=Ti, V, Zr) having a $L1_2$ crystal structure. These precipitates are coherent with the aluminium matrix. One of the very known alloys is Nasa



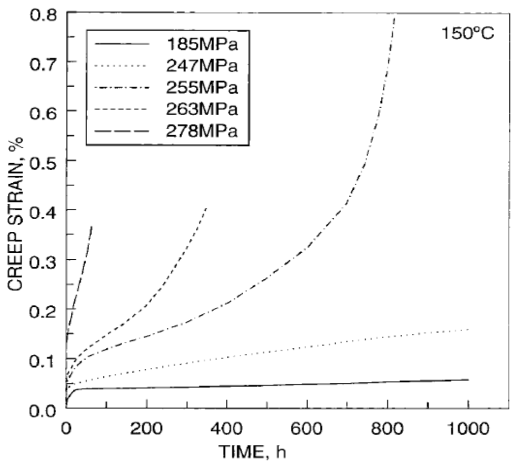
Slika 2. Visokotemperaturne lastnosti gnetne zlitine 2618 (Hiduminium RR 58), ki je primerjalna zlitina za temperaturno obstojne aluminijeve zlitine. a) Spreminjanje napetosti tečenja s časom in temperaturo (preizkusi so bili izvedeni pri povišani temperaturi b) Spreminjanje napetosti tečenja pri 200 °C in 250 °C (polne črte), in pri sobni temperaturi po izpostavitvi povišanih temperaturi (rekuperacija); rekuperacija 200 °C in 250 °C. [1]

Figure 2. The elevated temperature of the wrought alloy 2618 (Hiduminium RR 58), which represents a benchmark for heat resistant aluminium alloys. a) Dependence of the yield strength from time and temperature (the test were carried out at elevated temperature. b) Variation of yield strength at 200 °C and 250 °C (full lines), and at room temperature after exposure to elevated temperature; recovery 200 °C and 250 °C. [1]

po 100 h. Slika 3 prikazuje značilne krivulje lezenja.

Livne zlitine

Nasa je razvila serijo zlitin Al-Si, ki imajo izboljšane mehanske lastnosti pri povišanih temperaturah. Sestava patentirane zlitine je 6,0−25,0 % Si, 5,0−8,0%Cu, 0,05−1,2% Fe, 0,5−1,5 %Mg, 0,05−0,9%Ni, 0,05−1,2 % Mn, 0,05−1,2% Ti, 0,05−1,2%Zr, 0,05−1,2%V, 0,05−0,9 %Zn, 0,001−0,1 % Sr, 0,001−0,1 % P, razlika je aluminij [4]. Aluminijeva zlitina vsebuje disperzijo treh vrst izločkov Al_3X, kjer je X = Ti, V, Zr, ki imajo kristalno zgradbo $L1_2$. Ti izločki so koherentni z aluminijevo osnovo. Ena od zelo znanih zlitine je Nasa 238, ki ima pri 315 °C napetost tečenja 124 MPa in natezno trdnost 152 MPa.



Slika 3. Lastnosti lezenja preoblikovalne zlitine 2618 (Hiduminium RR 58) [1]

Figure 3. Creep properties of the wrought alloy 2618 (Hiduminium RR 58) [1]

Ave in sodelavci [5] so razvili novo evtektično aluminijevo zlitino Al-Cu-Si, ki lahko vsebuje do 1,5 % Ni in je primerna za uporabo v temperaturnem območju 300−400 °C. Sestava zlitine je Al-27%Cu-5%Si, ter do 1,5 % Ni. Pri strjevanju poteka ternarna evtektična reakcija L → q-Al_2Cu + a(Al) + b(Si). V zlitine, ki vsebujejo Ni, se pojavi še ternarna intermetalna spojina Al_7Cu_4Ni forms. Zlitina ima kar dobre trdnostne lastnosti pri 300 °C in 400 °C (300 °C: $R_{p0.2}$ = 267 MPa, R_m = 272 MPa, A = 4 %; 400 °C: $R_{p0.2}$ = 80 MPa, R_m = 104 MPa, A = 7 %). Te zlitine so precej boljše kot v primerjalni zlitini A319 (8,6 Si; 3.8 Cu; 0.3 Mn, 0,05 % Cr, 0,023 % Ni, 0,015 % Pb, 0,012 % Sr, 0,013 % Ti) z $R_{p0.2}$ = 91 MPa, R_m = 85 MPa, A = 8 % at 300 °C in 400 °C: $R_{p0.2}$ = 25 MPa, R_m = 25 MPa, A = 43 % pri 400 °C.

Casari in sodelavci [6] so študirali vpliv do 2 % Ni na mikrostrukturo in mehanske lastnosti zlitine A356 pri povišanih temperaturah. Ugotovili so, da dodatek Ni višji od 0.5 % zmanjša napetost tečenja $R_{p0.2}$ in natezno trdnost R_m v stanju T6. Zlitina z 0.5 % Ni je imala $R_{p0.2}$ = 180 MPa, R_m = 190 MPa, A < 4 % at 235 °C. Te lastnosti so bile podobne kot v standardni zlitini A356.

Bogdanoff in sodelavci [7] so raziskovali vpliv Co in Ni na mikrostrukturo in mehanske lastnosti hipoevtektične zlitine Al-Si7 pri sobni in povišanih temperaturah. Ugotovili so, da Co in Ni spremenita morfologijo evtektičnega silicija, ki ga lahko dodatno oplemeniti še Sr. Toda velikost kristalnih zrn se je povečala ob dodatku Co in Ni. Skupen dodatek Co in Ni je povišal R_m pri 230 °C za 32 %, kar je okoli 100 MPa. 1000-urna izpostavitev pri 240 °C je zmanjšala natezno trdnost na 60–70 MPa.

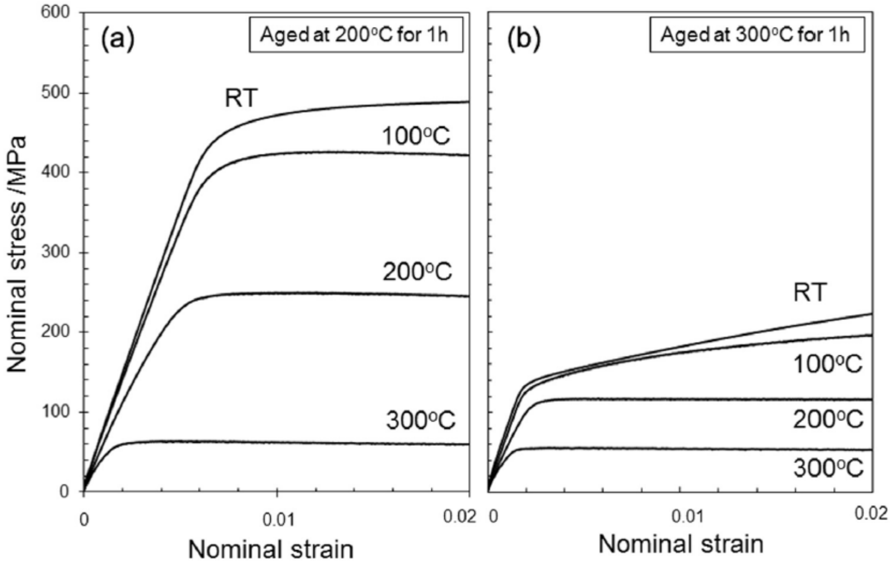
Jeong [8] je študiral učinek Cu, Ni in Ti na visokotemperaturne mehanske lastnosti zlitine za bate, ki je v bistvu zlitina na osnovi Al-Si (11.75–12.21 % Si). Ugotovil je, da se

238. At 315 °C, its yield strength is 124 MPa and tensile strength 152 MPa.

Ave et al. [5] have developed a new eutectic Al-Cu-Si, which can also contain up to 1.5 % Ni for high temperature performance from 300°C to 400 °C. The composition of the alloy is Al-27%Cu-5%Si, with up to 1.5wt.% Ni. During solidification occurs a ternary eutectic reaction L → θ-Al_2Cu + α(Al) + β(Si). In the Ni-bearing alloy also a ternary intermetallic compound Al_7Cu_4Ni forms. The alloy has rather high tensile properties at 300 °C and 400 °C (300 °C: $R_{p0.2}$ = 267 MPa, R_m = 272 MPa, A = 4 %; 400 °C: $R_{p0.2}$ = 80 MPa, R_m = 104 MPa, A = 7 %). This values are rather different in comparison to A319 alloy (8.6 wt.% Si; 3.8 wt.% Cu; 0.3 wt.% Mn, 0,05 wt.% Cr, 0,023 wt.% Ni, 0.015 wt.% Pb, 0,012 wt.% Sr, 0,013 wt.% Ti) with $R_{p0.2}$ = 91 MPa, R_m = 85 MPa, A = 8 % at 300 °C and 400 °C: $R_{p0.2}$ = 25 MPa, R_m = 25 MPa, A = 43 % at 400 °C.

Casari et al. [6] studied the effect of up to 2 wt.% Ni on the microstructure and high-temperature mechanical properties of A356 alloy. They found that Ni contents higher than 0.5 wt % yield a significant reduction in both $R_{p0.2}$ and R_m the T6 heat-treated alloys. The alloy with 0.5 wt.% Ni possessed $R_{p0.2}$ = 180 MPa, R_m = 190 MPa, A < 4 % at 235 °C. These properties were almost the same as in standard A356 alloy (Fig. 4).

Bogdanoff et al. [7] studied the effect of Co and Ni additions on the microstructure and mechanical properties of a hypoeutectic Al-Si7 alloy at room and elevated temperatures. They found that Co and Ni modified the eutectic silicon morphology, which can be further refined by the addition of Sr. However, the grain sizes increased by the additions of Co and Ni. The combined additions of Co and Ni increased R_m at 230 °C for 32 %, which was approximately 100 MPa. An exposure in duration of 1000



Slika 4. Lastnosti zlitine Al-Mn-Zn alloy. a) Staranje pri 200 °C, 1h, b) Staranje pri 300 °C, 1 h [9].

Figure 4. Properties of the Al-Mn-Zn alloy [9]. a) Ageing at 200 °C for 1 h, b) ageing at 300 °C for 1 h.

lastnosti močno povečajo pri dodatku teh zlitinskih elementov.

Takata in sodelavci [9] so razvili novo temperaturno obstojno zlitino Al-Mn-Zn alloy. To zlitino utrjujejo izločki T-$Al_6Mg_{11}Zn_{11}$ pri povišanih temperaturah. Preiskovana zlitina, ki je bila predstarana 1 h pri 200 °C je imela visoko napetost tečenja 260 MPa pri 200 °C. To je precej več kot običajne Al-zlitine (Fig. 4).

Druge aluminijeve zlitine

Zlitine Al-Cu-Li spadajo med najbolj perspektivne preoblikovalne toplotno obstojne aluminijeve zlitine. Balducci in sodelavci [10] so raziskali toplotno stabilnost toplotno obdelovalne zlitine 2099 v stanju T83. Po daljšem prestaranju je imela zlitina Al-Cu-Li boljše lastnosti kot aluminijeve zlitine za uporabo pri povišanih temperaturah, zraven tega pa je njena prednost, da ima še manjšo gostoto.

h at 240 °C reduced the tensile strength to 60–70 MPa.

Jeong [8] studied the effect of Cu, Ni and Ti on high-temperature mechanical properties for piston alloy, which is in fact an eutectic Al-Si alloy (11.75–12.21 wt.% Si). He found that the properties at elevated temperatures considerably increased with increased quantity of alloying elements.

Takata et al. [9] developed a novel heat-resistant aluminum alloy Al-Mn-Zn alloy. This alloy is strengthened by T-$Al_6Mg_{11}Zn_{11}$ precipitates at elevated temperatures. The investigated alloy (pre-aged at 200 °C for 1 h) exhibited high yield strength of approximately 260 MPa at 200 °C, much higher than those of the conventional Al alloys (Fig. 4).

Other Al-alloys

The Al-Cu-Li alloys belong to the most perspective wrought aluminium heat-

Ugotovili so, da 24-urna izpostavitev zlitine AA 2099 temperaturi 305 °C zmanjša R_m pri sobni temperaturi s 635 MPa na 266 MPa (72 HV), medtem ko pri zlitini AA2618 s 423 na 231 MPa (62 HV).

V zadnjem obdobju je v velikem interesu izboljšati lastnosti aluminijevih zlitin z dodajanjem skandija. Airbus je razvil več zlitin Al-Mg-Sc, med katerimi je povsem dozorela zlitina 5028 [11]. Te zlitine izdelajo z litjem na vrteče se kolo, visokotemperaturno ekstruzijo, valjanjem in toplotno obdelavo. Zlitine so utrjene z izločki Al_3Sc or $Al_3(Sc,Zr)$. Za zlitine so značilne visoka trdnost, velika toplotna stabilnost, dobra varivost in odlična korozijska obstojnost. Značilne lastnosti pri sobni temperaturi so $R_{p0.2}$ = 325 MPa, R_m = 400 MPa, A = 12 %.

V ternarni zlitini Al-Cu-Mn nastanejo izločki T-Al20Mn3Cu2 med toplotno obdelavo T5. Ti so toplotno stabilni pri povišanih temperaturah in lahko zagotovijo dobro toplotno obstojnost [12]. Belov in sodelavci so v zlitine Al-Cu-Mn dodajala Sc in Zr [13]. Poleg izločkov T-$Al_{20}Mn_3Cu_2$ so pri toplotni obdelavi T5 nastali tudi lupinasti izločki $Al_3(Sc,Zr)$, ki so še dodatno povečali trdnost in toplotno obstojnost. Zupanič in sodelavci [14] so odkrili kroglaste kvazikristalne izločke v zlitinah Al-Mn-Cu, ki vsebujejo tudi manjši delež Be. Kvazikristalni izločki se transformirajo v T-A $Al_{20}Mn_3Cu_2$ v T-$Al_{20}Mn_3Cu_2$ nad 450 °C. Ne glede na to lahko zagotovijo odlične visokotemperaturne lastnost najmanj do 350 °C.

Kvazikristali lahko nastanejo tudi med hitrim strjevanjem (pri litju na vrteče se kolo ali pri atomizaciji taline). Deli se lahko izdelajo ali s postopki prašne metalurgije s postopkom ekstruzije ali po drugih postopkih. Huo in Mais [15] sta poročala, da imajo lahko nekatere zlitine pri 400 °C natezno trdnost okoli 250 MPa.

Zelo trdne in toplotne obstojne zlitine je možno izdelati z napurševanjem. Yan resistant alloys. Balducci et al. [10] studied the thermal stability of T83 heat-treated 2099 alloy. After prolonged overaging, the alloy exhibited a better performance compared to aluminium alloys specifically developed for high temperature applications, with the advantage of a considerable lower density. They found that exposure to 305°C for 24 h reduces the R_m at room temperature from 635 MPa to 266 MPa (72 HV) AA 2099, and by AA2618 from 423 to 231 MPa (62 HV).

Over the last period, there is a great interest in improving properties of aluminium alloys with additions of scandium. Airbus developed several Al-Mg-Sc alloys, from which the alloy 5028 reached the status of maturation [11]. These alloys are produced by melt spinning, elevated temperature extrusion, rolling and heat treatment. They are strengthened by Al_3Sc or $Al_3(Sc,Zr)$ precipitates. The alloys are characterized by high-strength, high thermal stability, good weldability and excellent corrosion resistance. The typical properties at room temperature are $R_{p0.2}$ = 325 MPa, R_m = 400 MPa, A = 12 %.

In the ternary Al-Cu-Mn, T-$Al_{20}Mn_3Cu_2$ precipitates formed during T5 heat treatment. They are thermally stable at higher temperatures and can provide good heat resistance [12]. Belov et al. added Sc and Zr to Al-Cu-Mn alloys [13]. In addition to T-$Al_{20}Mn_3Cu_2$ precipitates, also core-shell $Al_3(Sc,Zr)$ precipitates during T5 heat treatment, which additionally increased strength and heat resistance. Zupanič et al. [14] discovered that spherical quasicrystalline precipitates can form during T5 heat treatment in cast Al-Mn-Cu alloy that contain a small amount of Be. The quasicrystalline precipitates transform to T-$Al_{20}Mn_3Cu_2$ above 450 °C. Nevertheless, they can provide excellent high temperature properties up to 350 °C.

in sodelavci [16] poročajo, da ima zlitina sestavljena iz 8,5 % Al, 8,5 Fe, 1,3 V in 1,7 % Si [zlitina FVS0812] pri 450 °C natezno trdnost kar 70 MPa. V tem primeru so bili deli izdelani z naprševanjem, ekstruzijo in končnim valjanjem.

Pomen dodajalnih tehnologij narašča. Pri kovinskih materialih je osnova droben kovinskih prah (kroglasti delci s premerom 20–40 mm). S selektivnim laserskim taljenjem (SLM) se lahko izdelajo zahtevne oblike. Pri selektivnem laserskem taljenju laser tali prah v plasteh. Poleg tega, da nastanejo zahtevne oblike, je dosti raziskav usmerjenih v to, kako izdelati načrtovano mikrostrukturo in lastnosti [17].

Obstojnost pri povišanih temperaturah se lahko doseže tudi z izdelavo kompozitov z aluminijevo osnovo. Primer je izdelava zlitin, ki ji dodajo CoNi delci [18].

Zaključna misel

Razvoj toplotno obstojnih Al-zlitin je dobil pospešek v zadnjih letih. Uporabijo se lahko v vesoljski in avtomobilski industriji, vse več aplikacij pa je v gradbeništvu, predvsem na področju ognjevzdržnih zlitin.

Najpomembnejše lastnosti so trdnost pri povišanih temperaturah, rekuperativna trdnost (trdnost pri sobni temperaturi po izpostavitvi na višjo temperaturo) in odpornost proti lezenju. Primerjava zlitin, ki so dostopne v literaturi, ni preprosta, kajti vplivni parametri testiranja navadno niso enaki. Potrebno je poudariti, da je visokotemperaturna trdnost odvisna od več dejavnikov, kot so hitrost segrevanja, čas zadrževanja na temperaturi preizkušanja ter hitrost deformacije.

Več Al-zlitin lahko zdrži mnogo višje temperature kot konvencionalne aluminijeve zlitine, ki izgubijo večino trdnosti pri segrevanju nad 250 °C. Mnoge od teh

Quasicrystals can also form during rapid solidification (melt spinning or melt atomisation). The parts can be produced via powder metallurgy route with further extrusion or other compaction methods. Huo and Mais [15] reported that the alloy has tensile strength at 400 °C as high as 250 MPa.

Very strong and heat resistant alloys can be produces by spray deposition. Yan et al. [16] reported that the Al-alloy with 8.5 wt.% Fe, 1.3 wt.% V and 1.7 wt.% Si [alloy FVS0812] possessed the tensile strength as high as 70 MPa at 450 °C. In this case the parts were produced by spray deposition, extrusion and rolling to the final size.

Additive manufacturing has been gaining importance. In case of metals, the basic material is fine metallic powder (spherical with diameters in the range 20–40 mm). Selective laser melting (SLM) can produce intricate shapes. By SLM, the laser melts the powder in layers. In addition to obtain very complex shapes, there are also many investigations how to design a microstructure and mechanical properties [17].

High temperature resistance can be also achieved by production of aluminium matrix composites. An example is manufacturing of alloys with CoNi particles [18].

Concluding remarks

The development of heat resistance Al-alloys obtained impetus over the last years. They can be applied in the aerospace and automotive industries, and the application are more often in construction, especially as fire resistant alloys.

The most important properties are strength at elevated temperatures, recovery strength (strength at room temperature after the exposure to an elevated temperature) so bile izdelane v laboratorijskem okolju, zato bo za njihov prenos v tehnično prakso potrebnega še nekaj časa. Kljub vsemu nastajajo obširni znanstveni temelji, ki lahko prinesejo pozitivne učinke na različnih področjih uporabe aluminijevih zlitin.

and creep resistance. Comparison between alloys published in the literature is not straightforward because testing conditions are usually not equal. It is import to stress that high-temperature strength depends on the heating rate, soaking time at the testing temperature and the strain rate during testing.

Several Al-alloys can withstand much higher temperatures than classical aluminium alloys that lose the most of their strength when heated to temperatures above 250 °C. Most of them were made in the laboratory scale, thus, for the application in the practise they will need some times. Nevertheless, there is a scientific basis for use of aluminium alloys at higher temperature, which can bring several benefits in different areas of application.

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