Раздел 1. «Металлургия»

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Production and use of reinforcing bars of strength class 500-600 MPa from steel with carbonitride hardening

An analytical review of the production of high-strength reinforcing bars from steel with carbonitride hardening is made, as well as an assessment of the requirements of new regulatory documents for this type of product, where new characteristics of properties are introduced. The main criteria that determine the applicability of rebar in construction are the characteristics of strength and deformability - relative uniform elongation or full relative elongation at maximum load, as well as the ratio of tensile strength to yield strength. The level of these properties is differentiated into three groups, this determines the applicability of reinforcing bars for buildings and structures for critical purposes, depending on climatic and seismic conditions. It has been established that the production of reinforcing bars of strength class 500-600 MPa from steel with carbonitride hardening significantly increases the consumer properties of the finished product (endurance, cold resistance, seismic resistance, fire resistance and fire safety). The use of reinforcing bars of strength class 500-600 MPa made of steel with carbonitride hardening provides an increase in the reliability of reinforced concrete structures, buildings and structures, especially during construction in regions with increased seismic activity and large differences in ambient temperatures. Attention is drawn to the fact that carbonitride hardening of steel, vanadium, niobium, molybdenum, etc. leads to a significant increase in the cost of finished products, which is an unprofitable measure for manufacturers of rebar. Such an expensive rental will not be competitive. A more correct and economically justified way is to carry out carbonitride hardening of reinforcing bars of strength class 500-600 MPa by alloying (modifying) steel with a system of elements - nitrogen, titanium and aluminum.

Key words: carbonitride hardening, rebar, strength class, seismic resistance, consumer properties, fire safety, cold resistance, endurance.

Introduction

In recent years, the production and consumption of rebar for reinforcing reinforced concrete structures has undergone significant changes, there has been a change in the requirements for consumer properties of this product. A large number of plants that use electric remelting and continuous casting of billets have greatly contributed to improving product quality, new regulations have been developed that have significantly increased the requirements for certain characteristics, which in turn determine the reliability of reinforcing bars [1, 2]. The main criteria that determine the reliability of rebar are the characteristics of deformability (relative uniform elongation (δ_p) or total relative elongation at maximum load (δ_{max}), as well as the ratio of tensile strength to yield strength ($\sigma_в/\sigma_{0,2}$). The level of these characteristics is divided into three groups, which determines the applicability of rebar rolling in the construction of buildings and structures for critical purposes, depending on climatic and seismic conditions. But, the ongoing tightening of requirements in the production of building structures poses a difficult task for the metallurgical industry, which is to create innovative steels for mass use. This will ensure the production of products with high consumer properties, namely: strength while maintaining plasticity in a wide temperature range, lowering the temperature threshold of brittleness, fatigue strength under static and dynamic loads, including alternating, corrosion resistance, etc. Ensuring the reliability requirements of reinforced concrete structures that work in extreme conditions is accompanied by a decrease in the metal intensity of production due to savings in materials [3-5].

Method and subject of research

Analytical studies were carried out according to available sources of information in order to justify the use of carbonitride hardening of steel for the production of reinforcing bars using an alloyed system that forms carbonitrides based on nitrogen, titanium and aluminum.

Results and discussion

1. The essence of carbonitride hardening and ways of implementation

The production of metal products of a high strength class without the use of steel alloying processes with substitution elements (Cr, Ni, Mo, etc.), which in turn are expensive, is achieved by implementing the mechanisms of dispersion and grain boundary strengthening. These mechanisms can be implemented by creating excess carbonitride phases during the alloying process of steel with the following elements, which have an increased affinity for carbon and nitrogen. To obtain high mechanical properties and performance characteristics for steel of the ferrite-pearlitic class, these types of steels are additionally alloyed with nitrogen (0.010-0.015%) and elements that form nitrides and carbonitrides. Vanadium, titanium, niobium, etc. act as such elements. In this case, ferrite grain refinement has a decisive influence on the full range of consumer properties of reinforcing bars (class 500-600 MPa), including strength. Ferrite grain refinement is provided by carbonitria, which have a regulating effect on the grain microstructure of the metal. The dispersion and amount of the excess phase is determined by the ratio of the phase-forming elements and the level of their concentrations, as well as the number of temperature regimes of rolling and thermomechanical treatment. Ordinary carbon steel can be microalloyed with titanium and aluminum. In this case, titanium determines the level of nitrogen solubility in the liquid metal and is responsible for the formation of carbonitride inclusions in the melt. Titanium also acts as a regulator of the size of the primary cast grain. Aluminum forms the grain structure of steel during thermomechanical processing of rebar. Also, aluminum nitrides form in solid metal. Along with high requirements for strength characteristics, it is important to increase the level of plastic properties of structural steel; this can only be possible with the introduction of carbonitride hardening technology based on nitrogen, titanium and aluminum.

2. Experience in the production of rebar from steels with carbonitride hardening

At present, rebars of strength class 500 MPa (class A500C, B500C) and 600 MPa (class A600C and B600C) are manufactured using traditional technologies and are delivered to consumers in the following conditions:

- hot-rolled state (without forced cooling after rolling), in thermally hardened state (with forced water cooling after rolling);
- cold-deformed state (rolled wire profiling at room temperature).

3. The level of consumer properties of AP from steels with carbonitride hardening

In modern construction, metal products are used for the construction of buildings and structures for civil and industrial purposes, as well as special objects are built (nuclear power plants, sea berths, high-rise buildings, etc.). At the same time, reinforcing bars with a wide range of high consumer properties are used. This issue is especially relevant during construction in regions with difficult climatic and seismic conditions. Therefore, in the newly developed regulatory documents for reinforcing bars [2], the concept of "an additional set of mechanical (consumer) properties" is specially introduced, which include cold resistance, endurance, seismic resistance, fire resistance and fire safety. In modern construction, increased attention is paid to the study of fire resistance and fire safety of reinforcing bars and regulatory documents are introduced to control and ensure these characteristics [5, 6, 14-16]. In [7], scientific studies were carried out to assess the mechanical and operational properties of A500C and A600C class reinforcing bars made of St3 grade steel, which was subjected to the process of microalloying with vanadium with varying concentration. Conducted tests for fire resistance and fire safety. The results obtained showed that an increase in the vanadium content to 0.11% provides a high level of fire safety up to 630 ° C, which indicates the high reliability of vanadium steel in reinforced concrete structures after fire exposure. Experiments were carried out in which the temperature threshold of fire resistance of the studied samples was determined. Increasing the content of vanadium to 0.11% has a positive effect on the value of the yield strength during tensile tests during thermal exposure. The papers [8-10] present the results of studies of the properties of reinforcing bars made of steel, which was subjected to the process of microalloying with vanadium. To determine additional characteristics, a series of experiments was carried out for corrosion resistance (class A500K), endurance (class A500U), fire resistance and fire safety (classes A500C and A500E). As a result of scientific research, it was found that reinforcing bar with carbonitride hardening meets the requirements of regulatory documents [2] in terms of mechanical properties to class A500E; reinforcing bars of classes A500K and A500E made of steels St3Gps, St3Gsp and 18G2S meet the requirements of regulatory documents [2] for resistance to corrosion cracking; for steels St3ps and St3Gsp, in terms of resistance to fatigue, repeatedly repeated cyclic loads, it meets the requirements of regulatory documents [2] for class A500U. The obtained scientific results on fire resistance and fire safety made it possible to establish the reliability of reinforcing bars to the effects of sudden heating. The papers [11-13] present the results of scientific research on the evaluation of the properties of An600S class reinforcing bars made of 20G2SFBA steel, which contains vanadium, niobium and molybdenum.

Based on numerous tests, it has been established:

- in terms of impact strength during testing for dynamic bending, the value of the work of destruction of prototypes significantly exceeds the normalized requirements for values even for special frost-resistant steels, in which impact strength at a temperature of -150°C remains at the level of 10 J/cm^2;

- unique tensile properties are demonstrated at low temperatures, while ductility is fully preserved;

- tests for endurance and low-cycle fatigue showed the validity of the use of An600C class reinforcing bars under seismic loads;

- when testing on the effect of heating, it was found that the mechanical properties of steel grade 20G2SFBA of the An600S class are retained even after heating to a temperature of 700 ° C, which is a characteristic of a material with increased fire resistance.

From the conducted analytical study, it can be concluded that the maximum increase in the consumer properties of ordinary steel grades through the use of carbonitride hardening [11].

4. Prospects for the consumption of AP from steels with carbonitride hardening

The presented results of the mechanical properties of reinforcing bars made of steels with carbonitride hardening indicate that carbonitride hardening is a significant way to improve the consumer properties of steel products. Based on the foregoing, in modern construction there is an increase in the consumption of reinforcing bars from steels with carbonitride hardening. When comparing the costs of implementing the process of carbonitride hardening of steel, it should be noted that alloying an ordinary steel grade with vanadium, niobium and molybdenum is an expensive way to improve the mechanical properties of metal products. An alternative way is to harden the steel by additional introduction of nitrogen, titanium and aluminum. The effectiveness of these measures has been proven in other sources [17, 18].

Conclusions

Based on the conducted analytical studies, the following can be concluded:

1. The production of reinforcing bars of strength class 500-600 MPa from steel with carbonitride hardening significantly increases the consumer properties of finished metal products (endurance, cold resistance, seismic resistance, fire resistance and fire safety).

2. The use of reinforcing bars of strength class 500-600 MPa from steel with carbonitride hardening provides an increase in the reliability of reinforced concrete structures, buildings and structures during construction in regions with increased seismic activity and climatic features in the form of large temperature differences.

3. Carbonitride hardening of steel with vanadium, niobium, molybdenum, etc. leads to a significant increase in the cost of finished metal products, and it can be concluded that such products will not be competitive.

4. The most rational and economically justified method is carbonitride hardening of rebar by modifying steel with nitrogen, titanium and aluminum.

Refernces

1 BS 4449:2005. Stal'nye izdeliya dlya armirovaniya betona. Svarivaemyj armaturnyj prokat. Prutki. Motki i vypryamlennye izdeliya : Tekhnicheskie usloviya // British Standards. 2005. — 36 s.

2 GOST 32028-2016. Prokat armaturnyj dlya zhelezobetonnyh konstrukcij. Tekhnicheskie usloviya (mezhgosudarstvennyj standart). − Moskva : Standartinform, – 2017. − 45 s.

3 Nikolaou J., Papadimitriou G. D. Microstructures and mechanical properties after heating of reinforcing 500 MPa class weldable steels produced by various processes (Tempcore, microalloyed with vanadium and work-hardened) //Construction and Building Materials (Stroitel'stvo i stroitel'nye materialy). – 2004. – T. 18. – №. 4. – S. 243-254.

4 Kozlov A. V. Ognestojkost' stal'nogo pro¬kata // Prokatnoe proizvod¬stvo. – 2004. – № 9. – S. 40–47.

5 STO 36554501-006-2006. Pravila po obespecheniyu ognestojkosti i ognesohrannosti zhelezobetonnyh konstrukcij. M.: FGUP "NIC "Stroitel'stvo". - 2006. - 78 s.

6 Pat. 2175359 RF. MPK C22C 38/12; C22C 38/46; C21C 5/04; C21C 5/28; C21C 7/06. Armaturnaya goryachekatanaya stal' i sposob vyplavki stali dlya ee polucheniya // A.A. Kamenskih, A.A. Karpov, E.A. Vasin i dr.; zayavl. 17.04.2000; opubl. 27.10.2001, Byul. №30.

7 Domov D.V. Vliyanie vanadiya na mekhanicheskie i potrebitel'skie svojstva svarivaemoj armaturnoj stali klassov prochnosti A500S i A600S / Domov D.V., Frantov I.I., Seregin A.N. i dr. // Metallurg. 2015. - №10. S. 65-69.

8 Hamichonok V.V., Matveev N.G., Mirochnik I.A., CHinokalov E.V. Razrabotka tekhnologii proizvodstva armaturnogo prokata klassa A500 s kompleksom dopolnitel'nyh svojstv po GOST 34028–2016 v usloviyah AO EVRAZ ZSMK // CHernaya metallurgiya. Byulleten' nauchno-tekhnicheskoj i ekonomicheskoj informacii. 2019. №6. S. 711–717.

9 Madatyan S.A. Novaya norma stroitel'nogo rynka // Stroitel'nyj Ezhenedel'nik , 27 08 2012, 33 (525).

10 Pat. 2478727RF. MPK S22S 38/12, S21D 8/06. Vysokoprochnyj svarivaemyj armaturnyj profil' / S.A. Madatyan, L.A. Zborovskij, D.E. Klimov i dr.; zayavl. 02.03.2012; opubl. 10.04.2013 Byul. №10.

11 Vodovozova G.S., Kopytova N.V., Madatyan S.A., Klimov D.E. Universal'naya armaturnaya stal' klassa An600S marki 20G2SFBA // CHernaya metallurgiya. Byulleten' nauchno-tekhnicheskoj i ekonomicheskoj informacii. 2016. №5. S.51-56.

12 Ivchenko A.V. Proizvodstvo effektivnyh vidov metalloprodukcii putem holodnoj deformacii zagotovki povyshennoj prochnosti iz ryadovyh marok stalej s karbonitridnym uprochneniem / Ivchenko A.V., Rabinovich A.V., Ambrazhej M.YU. i dr. // Byulleten' nauchno-tekhnicheskoj i ekonomicheskoj informacii «CHernaya metallurgiya». –2008. –№10. –S. 50-53.

13 Ivchenko A.V. K voprosu o proizvodstve holodnodeformirovannogo armaturnogo prokata iz katanki s karbonitridnym uprochneniem / A.V. Ivchenko, A.V. Rabinovich, M.YU. Ambrazhej i dr. // Metizy. –2010. –№1(22). –S. 50-53.

14 Ivchenko A.V. Gul' YU.P., Pankov R.V., Kondratenko P.V. Ognesohrannost' holodnodeformirovannogo armaturnogo prokata klassa V500S // Beton i zhelezobeton v Ukraine. 2015. №5. C. 24-29.

15 Kuznecova I.S., Surikov I.N., Vostrov M.S., Savrasov I.P. Issledovanie fiziko-mekhanicheskih svojstv armatury sovremennogo proizvodstva pri vysokotemperaturnom nagreve i ohlazhdenii // Promyshlennoe i grazhdanskoe stroitel'stvo. 2016. №12. S. 18-23.

16 Ivchenko A.V. Ognestojkost' holodnodeformirovannogo armaturnogo prokata klassa V500S / Ivchenko A.V., Gul' YU.P., YAkushev A.S., Kovalenko V.F., Savrasov I.P., Vostrov M.S. // Metallurgicheskaya i gornorudnaya promyshlennost', 2017. №1. S. 71-76.

17 Bublikov YU.A., Ivchenko A.V. Proizvodstvo metalloprodukcii iz stalej s karbonitridnym uprochneniem / LAMBERT Academic Publishing. Dyussel'dorf. 2020.153 c.

18 Ivchenko A.V., Bublikov YU.A. O celesoobraznosti proizvodstva i primeneniya armaturnogo prokata klassa prochnosti 500-600 MPa iz stali s karbonitridnym uprochneniem // Vestnik Karagandinskogo gosudarstvennogo industrial'nogo universiteta. 2021. №3 (34). S. 28-34.

Раздел 1. «Металлургия»

А.В. Ивченко, Ю.А. Бубликов

Карбонитридті беріктігі бар болаттан жасалған 500-600 МПа беріктік класындағы арматуралық илемді өндіру және қолдану

Карбонитридті нығайтылған болаттан жасалған беріктігі жоғары арматуралық прокат өндірісіне аналитикалық шолу жасалды, сондай-ақ қасиеттердің жаңа сипаттамалары енгізілген өнімнің осы түріне жаңа нормативтік құжаттардың талаптарын бағалау орындалды. Құрылыста арматуралық Илемдеудің қолданылуын анықтайтын негізгі критерийлер беріктік пен деформацияның сипаттамалары болып табылады-максималды жүктеме кезінде салыстырмалы біркелкі ұзарту немесе толық салыстырмалы ұзарту, сондай-ақ уақытша қарсылық пен аққыштық коэффициенті. Бұл қасиеттердің деңгейі үш топқа бөлінеді, бұл климаттық және сейсмикалық жағдайларға байланысты жауапты мақсаттағы ғимараттар мен құрылыстар үшін арматуралық прокаттың қолданылуын анықтайды. Карбонитридті беріктігі бар болаттан жасалған 500-600 МПа беріктік класындағы арматуралық илемдеу өндірісі дайын өнімнің тұтынушылық қасиеттерін (төзімділік, суыққа төзімділік, жер сілкінісіне төзімділік, отқа төзімділік және отқа төзімділік) едәуір арттыратыны анықталды. Карбонитридті беріктігі бар болаттан жасалған 500-600 МПа беріктік класындағы арматуралық илемді қолдану темірбетон конструкцияларының, ғимараттар мен құрылыстардың сенімділігін арттыруды қамтамасыз етеді, әсіресе сейсмикалық белсенділігі жоғары және қоршаған орта температурасының үлкен айырмашылықтары бар аймақтарда құрылыс кезінде. Болаттың, ванадийдің, ниобийдің, молибденнің және т.б. карбонитридті қатаюы дайын өнімнің өзіндік құнының айтарлықтай өсуіне әкелетініне назар аударылады, бұл арматуралық прокат өндірушілері үшін тиімсіз шара болып табылады. Мұндай қымбат жалдау бәсекеге қабілетті болмайды. 500-600 МПа беріктік класындағы арматуралық илемді карбонитридті қатайтуды элементтердің жүйесі - азот, титан және алюминиймен допинг (модификациялау) арқылы жүргізу неғұрлым дұрыс және экономикалық негізделген әдіс болып табылады.

Түйінді сөздер: карбонитридті қатайту, арматуралық илемдеу, беріктік класы, жер сілкінісіне төзімділік, тұтынушылық қасиеттері, отқа төзімділік, суыққа төзімділік, төзімділік.

А.В. Ивченко, Ю.А. Бубликов

Производство и применение арматурного проката класса прочности 500-600 МПа из стали с карбонитридным упрочнением

Сделан аналитический обзор производства арматурного проката повышенной прочности из стали с карбонитридным упрочнением, а также исполнена оценка требований новых нормативных документов к данному виду продукции, где введены новые характеристики свойств. Основными критериями, которые определяют применимость арматурного проката в строительстве, являются характеристики прочности и деформативности - относительное равномерное удлинение или полное относительное удлинение при максимальной нагрузке, а также соотношение временного сопротивления к пределу текучести. Уровень данных свойств, дифференцирован по трем группам, это определяет применимость арматурного проката для зданий и сооружений ответственного назначения в зависимости от климатических и сейсмических условий. Установлено, что производство арматурного проката класса прочности 500-600 МПа из стали с карбонитридным упрочнением значительно повышает потребительские свойства готовой продукции (выносливость, хладостойкость, сейсмостойкость, огнестойкость и огнесохранность). Применение арматурного проката класса прочности 500-600 МПа из стали с карбонитридным упрочнением обеспечивает увеличение надежности железобетонных конструкций, зданий и сооружений, особенно при строительстве в регионах с повышенной сейсмической активностью и большими перепадами температур окружающей среды. Указано внимание на то, что карбонитридное упрочнение стали, ванадием, ниобием, молибденом и др. приводит к существенному увеличению себестоимости готовой продукции, что является нерентабельным мероприятием для производителей арматурного проката. Такой дорогой прокат будет не конкурентоспособным. Более правильным и экономически обоснованным способом является проводить карбонитридное упрочнение арматурного проката класса прочности 500-600 МПа путём легирования (модифицирования) стали системой элементов - азотом, титаном и алюминием.

Ключевые слова: карбонитридное упрочнение, арматурный прокат, класс прочности, сейсмостойкость, потребительский свойства, огнесохранность, хладостойкость, выносливость.

Литература

1 BS 4449:2005. Стальные изделия для армирования бетона. Свариваемый арматурный прокат. Прутки. Мотки и выпрямленные изделия : Технические условия // British Standards. 2005. — 36 с.

2 ГОСТ 32028-2016. Прокат арматурный для железобетонных конструкций. Технические условия (межгосударственный стандарт). − Москва : Стандартинформ, – 2017. − 45 с.

3 Nikolaou J., Papadimitriou G. D. Microstructures and mechanical properties after heating of reinforcing 500 MPa class weldable steels produced by various processes (Tempcore, microalloyed with vanadium and work-hardened) //Construction and Building Materials (Строительство и строительные материалы). – 2004. – Т. 18. – №. 4. – С. 243-254.

4 Козлов А. В. Огнестойкость стального проката // Прокатное производство. – 2004. – № 9. – С. 40–47.

5 СТО 36554501-006-2006. Правила по обеспечению огнестойкости и огнесохранности железобетонных конструкций. М.: ФГУП "НИЦ "Строительство". - 2006. - 78 с.

6 Пат. 2175359 РФ. МПК C22C 38/12; C22C 38/46; C21C 5/04; C21C 5/28; C21C 7/06. Арматурная горячекатаная сталь и способ выплавки стали для ее получения // А.А. Каменских, А.А. Карпов, Е.А. Васин и др.; заявл. 17.04.2000; опубл. 27.10.2001, Бюл. №30.

7 Домов Д.В. Влияние ванадия на механические и потребительские свойства свариваемой арматурной стали классов прочности А500С и А600С / Домов Д.В., Франтов И.И., Серегин А.Н. и др. // Металлург. 2015. -№10. С. 65-69.

8 Хамичонок В.В., Матвеев Н.Г., Мирочник И.А., Чинокалов Е.В. Разработка технологии производства арматурного проката класса А500 с комплексом дополнительных свойств по ГОСТ 34028–2016 в условиях АО ЕВРАЗ ЗСМК // Черная металлургия. Бюллетень научно-технической и экономической информации. 2019. №6. С. 711–717.

9 Мадатян С.А. Новая норма строительного рынка // Строительный Еженедельник , 27 08 2012, 33 (525).

10 Пат. 2478727РФ. МПК C22C 38/12, C21D 8/06. Высокопрочный свариваемый арматурный профиль / С.А. Мадатян, Л.А. Зборовский, Д.Е. Климов и др.; заявл. 02.03.2012; опубл. 10.04.2013 Бюл. №10.

11 Водовозова Г.С., Копытова Н.В., Мадатян С.А., Климов Д.Е. Универсальная арматурная сталь класса Ан600С марки 20Г2СФБА // Черная металлургия. Бюллетень научно-технической и экономической информации. 2016. №5. С.51-56.

12 Ивченко А.В. Производство эффективных видов металлопродукции путем холодной деформации заготовки повышенной прочности из рядовых марок сталей с карбонитридным упрочнением / Ивченко А.В., Рабинович А.В., Амбражей М.Ю. и др. // Бюллетень научно-технической и экономической информации «Черная металлургия». –2008. –№10. –С. 50-53.

13 Ивченко А.В. К вопросу о производстве холоднодеформированного арматурного проката из катанки с карбонитридным упрочнением / А.В. Ивченко, А.В. Рабинович, М.Ю. Амбражей и др. // Метизы. –2010. –№1(22). –С. 50-53.

14 Ивченко А.В. Гуль Ю.П., Панков Р.В., Кондратенко П.В. Огнесохранность холоднодеформированного арматурного проката класса В500С // Бетон и железобетон в Украине. 2015. №5. С. 24-29.

15 Кузнецова И.С., Суриков И.Н., Востров М.С., Саврасов И.П. Исследование физико-механических свойств арматуры современного производства при высокотемпературном нагреве и охлаждении // Промышленное и гражданское строительство. 2016. №12. С. 18-23.

16 Ивченко А.В. Огнестойкость холоднодеформированного арматурного проката класса В500С / Ивченко А.В., Гуль Ю.П., Якушев А.С., Коваленко В.Ф., Саврасов И.П., Востров М.С. // Металлургическая и горнорудная промышленность, 2017. №1. С. 71-76.

17 Бубликов Ю.А., Ивченко А.В. Производство металлопродукции из сталей с карбонитридным упрочнением / LAMBERT Academic Publishing. Дюссельдорф. 2020.153 с.

18 Ивченко А.В., Бубликов Ю.А. О целесообразности производства и применения арматурного проката класса прочности 500-600 МПа из стали с карбонитридным упрочнением // Вестник Карагандинского государственного индустриального университета. 2021. №3 (34). С. 28-34.