

## RAPID DAMAGED-BUILDING RESTORATION WITH EFFICIENT EQUIPMENT FOR RESOURCE-SAVING STEEL-REINFORCED CONCRETE STRUCTURES

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This scientific study presents an analysis of the current state and development prospects of equipment for concrete mix and construction mortar preparation, transportation, and vibration compaction in the context of its adaptation to European standards requirements implemented in Ukraine. Primary attention is focused on mechanical and mechanochemical activation research of concrete mix components under high-intensity forced-action mixer application conditions, as well as pipeline transportation parameter and vibration compaction mode influence on mix structural-rheological characteristics and cement stone formation process. Planetary, twin-shaft, and rotary mixer kinematic schemes and material interaction features within construction mix preparation technological system configurations are analysed. The applicability of Viscoprobe-type rheological property online monitoring systems and the discrete element method (DEM) for mix behaviour prediction at mixing, transportation, and compaction stages is demonstrated. The influence of combined mixing, delivery, and vibration parameter interaction on structural formation process acceleration and concrete physical-mechanical property improvement, including high-performance (HPC) and ultra-high-performance (UHPC) composites, is substantiated. The obtained results can be applied for rational operating parameter justification of technological system configurations for resource-saving steel-reinforced concrete structure production for rapid damaged-building restoration considering national raw material base features.

**Key words:** concrete mix, mortar, mixing, transportation, pump, vibratory compaction, vibrator, discrete element method, resource-saving technologies, restoration.

**Problem statement.** The current stage of Ukraine's construction industry development is characterized by unprecedented challenges associated with the need for large-scale destroyed infrastructure, housing stock, and industrial facility reconstruction. This process occurs against the background of regulatory framework deep transformation aimed at full harmonization with European standards. Implementation of DSTU EN 206:2022 and harmonized DSTU

EN 12350-8:2022 and DSTU EN 12390-1:2024 standards has significantly changed the concrete structure quality assurance approach, shifting it from strength control toward durability provision, concrete mix rheological characteristic stability assurance, and service-condition compliance [1-3].

Previously, compressive strength grade served as the primary quality criterion, whereas current standards impose integrated requirements for durability,

watertightness, frost resistance, and, most importantly, concrete mix characteristic consistency over time [4]. Modern multicomponent concrete application (High Performance Concrete – HPC, Ultra-High Performance Concrete – UHPC), fiber-reinforced concrete, and self-compacting concrete (SCC) is impossible without high-technology equipment for concrete mix and construction mortar preparation, transportation, and vibration processing. Traditional gravity mixing methods that dominated the previous century have exhausted their technological potential and cannot ensure required microcomponent homogeneity and binder activation, which significantly complicates subsequent concrete mix and construction mortar pipeline transportation, reduces transportation-stage rheological characteristic stability, and leads to increased energy consumption and uneven mix supply to construction machine working units.

Insufficient mix homogeneity and structural instability also adversely affect subsequent vibration processing efficiency, reducing particle redistribution intensity within the medium, worsening compaction conditions, and complicating required density and strength achievement of formed construction structures [5].

The construction material mixing process is no longer considered a simple mechanical component distribution operation. Instead, it is interpreted as a complex set of physical, chemical, and physico-mechanical processes resulting in uniform mineral aggregate component and binder (cement) distribution within the volume, forming a structure with minimal defect content. However, the most controllable and potentially effective lever of influence on final product quality remains concrete mix mechanical processing at the preparation stage.

Subsequent concrete mix and construction mortar pipeline transportation should also be considered an active stage of structural-rheological property formation, since pumping conditions determine mix homogeneity preservation degree, flow-regime characteristics, and working-zone supply uniformity during construction operations. At the same time, final-stage vibration impact on the mix ensures compaction process intensification, promotes excess air removal from its structure, and increases formed construction material density and strength.

The relevance of this study is determined by the need for scientific justification of modern concrete mixing equipment selection and operating modes capable of implementing mechanical activation effects, as well as concrete mix and construction mortar pipeline transportation parameter and final-

stage vibration processing mode justification within the technological cycle. This will not only improve concrete and mortar physical-mechanical characteristics, ensure construction machine working-unit mix supply uniformity and compaction efficiency, but also optimize energy-intensive Portland cement consumption, which is critically important under energy constraint conditions and current environmental requirements, particularly carbon footprint reduction requirements.

**Review of Research Resources and Publications.** Scientific and technical source and construction equipment market analysis indicates that global leadership in innovative mixing system development belongs to Western European countries (Germany, Italy, France, Denmark). Companies such as Skako, Simem, Liebherr, Schlosser-Pfeiffer, and Couvrot have integrated tribology, hydrodynamics, and materials science research developments into their machine designs [6].

Fundamental mineral binder mechanical activation process research conducted by Ukrainian scientists – Ivan V. Barabash (Odessa State Academy of Civil Engineering and Architecture school) and Leonid Y. Dvorkin (National University of Water and Environmental Engineering school) – demonstrates that intensive mechanical impact on water-cement suspension can significantly modify hydration kinetics. Cement stone strength gain under activation conditions can reach 20–30%, while 28-day chemically bound water content increases from 13% to 17.9% [7-10].

Modern international research focuses on digital mixing process modeling. Discrete Element Method (DEM) application enables individual particle motion visualization within the mixer, blade geometry optimization, and dead-zone identification [11]. Simulation results correlate with laboratory test data and show convection reinforced by radial and vertical circulation as the dominant mixing mechanism in planetary mixers. At the same time, modern research extends to digital modeling of concrete mix and construction mortar pipeline transportation processes, enabling flow-channel geometric parameter, pressure drop, and medium rheological characteristic influence evaluation on mix motion patterns and pumping equipment energy performance indicators. A separate research direction involves construction mix vibration impact modelling, enabling rational oscillation frequency and amplitude parameter determination for material compaction intensification and defect-free dense internal structure formation [12].

At the same time, available literature insufficiently addresses imported high-intensity mixer

operating mode adaptation to Ukrainian aggregate characteristics, particularly different grain-shape granite crushed stone and different-origin sand properties. The practical implementation aspect of rheological online-control systems (Viscoprobe-type) at domestic concrete plants for DSTU EN 206:2022 compliance assurance also requires more detailed consideration.

**Purpose of the work** – development of scientific-methodological principles for efficient concrete mixing equipment selection and operation for construction mix preparation required for two-stage technology resource-saving steel-reinforced concrete structure production for rapid damaged building floor restoration, as well as rational concrete mix and construction mortar pipeline transportation parameter and final-stage structural formation vibration processing mode justification to ensure uniform mix supply, efficient material compaction, and restored structural element performance characteristic improvement.

**Discussion of research results.** Structure formation is performed in two sequential stages with stepwise concrete mix placement, ensuring controlled system element stress–strain state variation and favorable condition creation for self-stress development without additional reinforcement or energy-intensive prestressing methods. At the same time, concrete mix and construction mortar transportation modes to the placement zone play an important role, ensuring mix homogeneity preservation and supply uniformity, while placement-stage vibration impact parameters promote efficient material compaction, porosity reduction, and dense concrete structure formation with enhanced floor structural performance characteristics.

Part of the section (steel beams or profiled decking) within concreting zones deflects downward under freshly placed concrete self-weight, thereby forcing adjacent unloaded steel section zones to bend upward. After first-stage concrete placement design strength attainment, subsequent floor section concreting is performed. At this stage, concreting zones deflect downward under freshly placed concrete self-weight, thereby forcing first-stage concreting zones with composite steel-reinforced concrete sections to bend upward. Adjacent span deflection magnitudes can be predicted by selected steel and composite steel-reinforced concrete section stiffness parameters, as well as support stiffness characteristics. Under service load, the formed composite steel-reinforced concrete structure will operate with existing prestress, providing the expected resource-saving

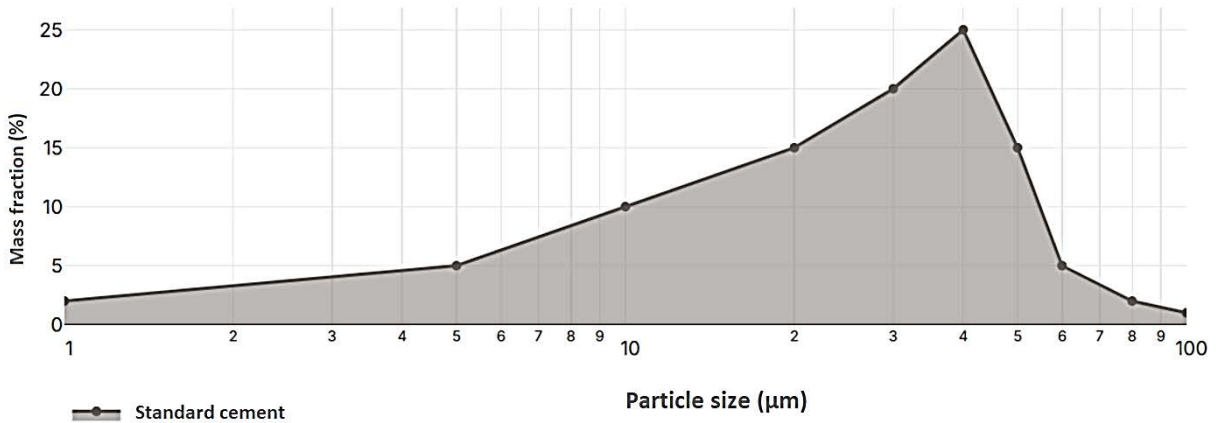
effect of the developed two-stage monolithic slab construction method. The considered two-stage monolithic slab concreting technology therefore requires detailed evaluation of efficient concrete mix preparation equipment, as well as rational concrete mix and construction mortar placement-zone transportation parameter and placement-stage vibration processing mode justification ensuring required mix homogeneity, efficient material compaction, and design composite steel-reinforced concrete floor structure formation [13].

Concrete mix preparation is traditionally considered polydisperse system homogenization (Fig. 2). However, transition to the “concrete-as-composite” concept requires deeper understanding of phase-boundary processes occurring not only during mixing but also during concrete mix and construction mortar transportation stages and subsequent vibration compaction. Mechanical activation (MA) is a process of solid-phase reactivity modification caused by structural defect accumulation and surface energy state variation under mechanical energy action, realized under intensive forced mixing conditions, maintained during pipeline pumping due to flow shear stress effects, and further manifested under placement-stage vibration impact during structural formation. From the point of mixing view, mechanical activation is realized through three main mechanisms possible only under intensive mechanical action of mixer working units, pumping equipment, and vibration devices [14].

Cement floc deagglomeration occurs due to high shear stress generation during forced mixing, concrete mix and construction mortar pipeline transportation, and vibration compaction, resulting in cement grain aggregate destruction, water access provision to individual grains, and effective hydration surface area increase by 30–50% without cement grinding fineness modification. Surface abrasive cleaning is realized due to intensive friction between aggregate and cement grains not only in high-speed mixers but also during pipeline mixture pumping and vibration oscillation action, promoting primary hydrate shielding film destruction, clinker mineral exposure, and hydration induction-period reduction. Aggregate energetic activation occurs due to mixer working-unit impact interaction with the material, as well as additional dynamic effects during transportation and vibration compaction, resulting in inert aggregate surface microcrack and dislocation formation and new-phase crystallization active-center development within the cement stone–aggregate contact zone.



**Fig. 1. Stages of resource-saving built-in composite steel-reinforced concrete floor construction: a) load-bearing steel beam layout; б) monolithic reinforced concrete slab working reinforcement installation; в) monolithic slab concreting process; г) general view of the slab immediately after concrete mix placement and compaction**



**Fig. 2. Cement particle size distribution curve**

Mathematically, mixing and activation efficiency can be described through energy dissipation per unit mix volume ( $E_v$ ):

$$E_v = \int_0^t \mu_{eff} \cdot \gamma^2 dt \quad (1)$$

where  $\mu_{eff}$  – effective mix viscosity,  
 $\gamma$  – shear rate gradient,  
 $t$  – mixing time.

It is the parameter that  $\gamma$  is critical: in gravity mixers it is units of  $s^{-1}$ , while in modern

forced mixers (rotary, planetary) it reaches values of  $102 - 103 s^{-1}$ .

Modern concrete mixing equipment analysis shows that forced-action batch mixers are the most efficient for construction mix preparation intended for two-stage technology self-stressed composite steel-reinforced concrete structure construction.

These include planetary, twin-shaft, and turbine mixers providing intensive energetic impact on the mix, promoting cement particle deagglomeration,

aggregate surface activation, and homogeneous medium structure formation. Rational mixer kinematic scheme selection determines mix component mechanical activation level and significantly influences hydration process kinetics and subsequent cement stone physical-mechanical characteristics.

An important component of the technological system configuration is equipment for concrete mix and construction mortar pipeline transportation, whose operating parameters must ensure mix structural-rheological characteristic stability during placement-zone supply. Flow-channel geometric parameters, pressure drop magnitude, and medium flow regime determine transportation process energy consumption, material supply uniformity, and homogeneity preservation degree, which is a decisive factor in structural performance characteristic formation of structures produced by two-stage concreting technology.

The final stage of composite steel-reinforced concrete structure formation is concrete mix vibration

compaction, whose efficiency depends on vibration equipment structural parameters and operating modes. Rational oscillation frequency and amplitude selection ensures particle redistribution intensification within the medium, excess air removal from mix volume, porosity reduction, and dense cement stone microstructure formation directly affecting restored composite steel-reinforced concrete floor load-bearing capacity and durability [15].

Combined intensive mixing, stable pipeline transportation, and rational vibration compaction mode interaction ensures concrete mix homogeneity improvement and formed structure strength development acceleration, as confirmed by the results shown in Fig. 4. In particular, forced-action mixer application compared with traditional gravity mixers increases mix homogeneity coefficient, while additional component mechanical activation effects promote significant early-stage concrete strength gain. At the same time, structural-rheological characteristic stability during

Table 1

Mixer type comparison

Mixer type	Mixing mechanism	Advantages	Limitations	Main application
Planetary	Convection + shear (complex trajectory)	Highest homogeneity, efficient fine-fraction processing	Maintenance complexity, lower productivity	Precast reinforced concrete, paving blocks, architectural concrete
Twin-shaft	Turbulence + pseudo liquefaction	High productivity, reliability, large-aggregate capability	Shaft seal wear, difficulties with coloured mixes	Ready-mix concrete, massive reinforced concrete, road concrete
Rotary (Eirich)	Dispersion + granulation	Maximum intensity and activation level	High cost, high energy consumption	UHPC, refractories, special mixes

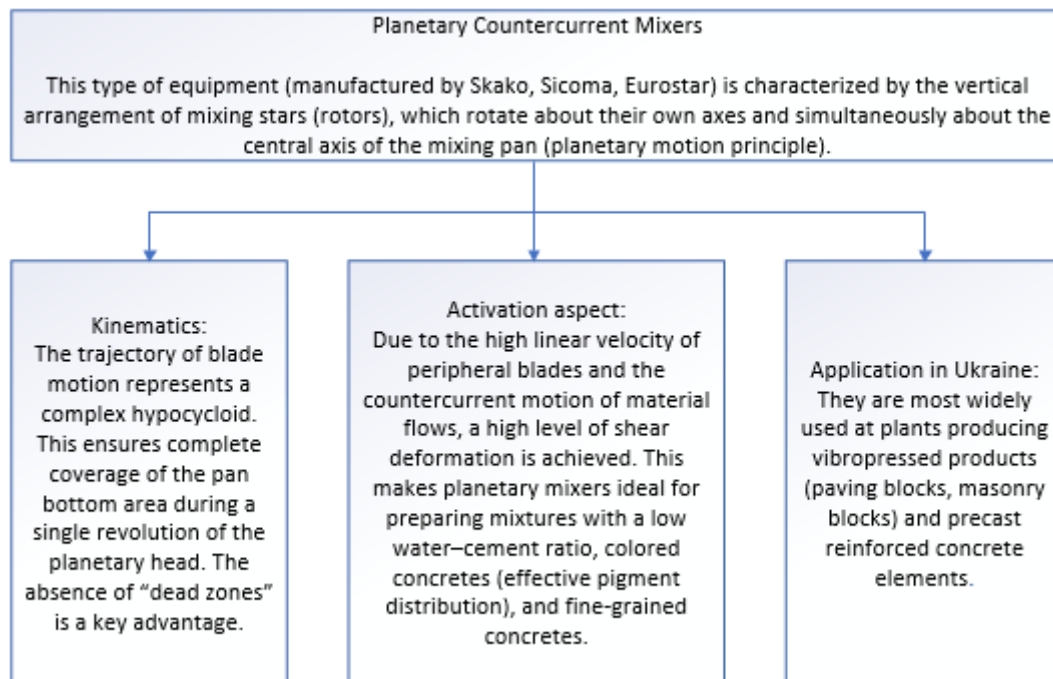


Fig. 3. Planetary countercurrent mixer characteristics: operating principle, kinematics, and application

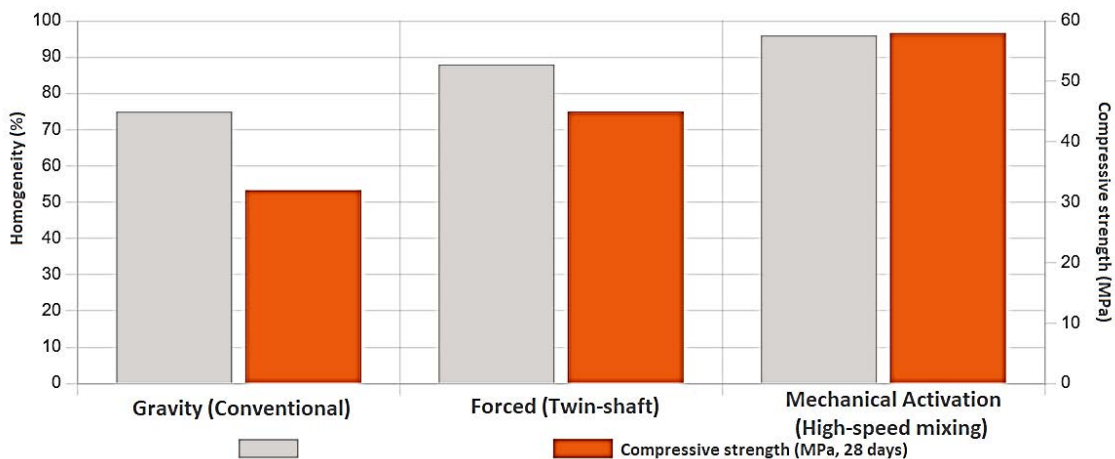


Fig. 4. Strength development and homogeneity comparison

pipeline transportation ensures placement-zone supply uniformity without segregation or homogeneity loss, while rational vibration impact parameters promote efficient air inclusion removal and dense cement stone structure formation. Combined technological factor interaction creates favourable conditions for composite steel-reinforced concrete structure physical-mechanical characteristic improvement under two-stage technology production.

Concrete mix quality stability under aggregate moisture variability conditions (especially sand) is a critical problem not only at the mixing stage but also during subsequent pipeline transportation and placement-stage vibration compaction. Medium rheological parameter variation at any of these stages can lead to material supply uniformity disturbance, transportation energy consumption increase, and structural compaction efficiency reduction. Traditional microwave moisture sensors do not always ensure required control accuracy of such variations. Modern control paradigm is based on in-mixer rheology measurement with subsequent mix behaviour prediction during transportation and compaction stages.

A representative example of such technology is the Viscoprobe system developed by Convi (part of the Skako group). Viscoprobe is an active sensor installed on a mixing blade or a dedicated holder inside the mixer chamber. The device measures drag force acting on the probe during its movement through the concrete mix. Unlike indirect methods (mixer motor current measurement – wattmeter-based systems) dependent on gearbox condition, belt tension, and filling degree, Viscoprobe provides direct medium resistance data, enabling prompt mixing parameter adjustment and rheological characteristic stability assurance during subsequent pipeline transportation and placement-stage vibration compaction.

Concrete mix quality control and viscosity adjustment (Fig. 5) are based on the Bingham rheological model describing concrete mix behaviour:

$$\tau = \tau_0 + \mu_p \cdot \dot{\gamma} \tag{2}$$

where  $\tau$  – shear stress (sensor-measured);  
 $\tau_0$  – dynamic yield stress correlated with slump cone value;  
 $\mu_p$  – plastic viscosity characterizing mix resistance to flow under external force action.

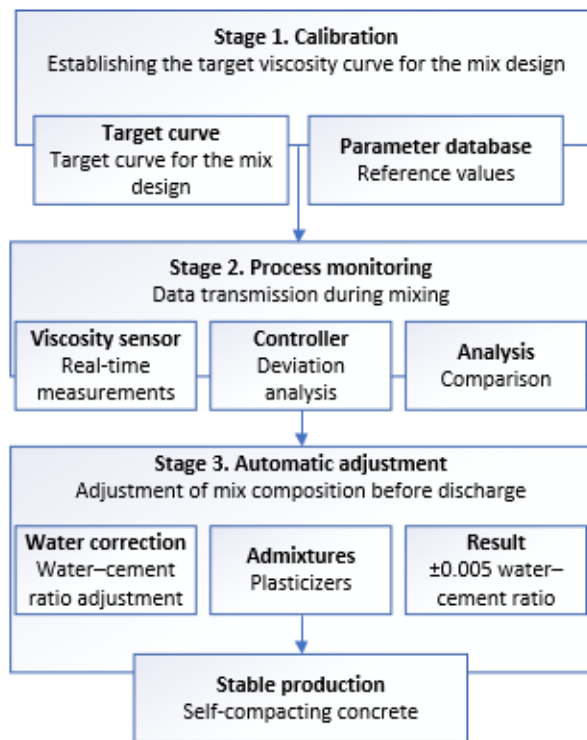


Fig. 5. Automatic viscosity control and adjustment scheme in self-compacting concrete production

New mixer design development is no longer performed by trial-and-error methods. Leading manufacturers, including Schlosser-Pfeiffer and Liebherr, apply the Discrete Element Method (DEM) for mixing process digital twin creation and particle behaviour prediction within the mixer working volume.

The Discrete Element Method (DEM) is based on individual particle motion trajectory and interaction calculation in a Lagrange coordinate system considering friction forces, elasticity (Hertz–Mindlin model), cohesion (SJKR model for wet materials), and gravity. Simulation enables particle velocity-field determination throughout the mixer volume, collision intensity (activation energy) evaluation, material stagnant-zone identification, and working-unit wear prediction. The obtained modelling results create prerequisites for mixing device geometric parameter optimization and rational construction mix preparation mode development.

An important advantage of DEM application is post-mixing structural-rheological state prediction capability, enabling mix behaviour evaluation during subsequent pipeline transportation and vibration compaction conditions. This ensures mixing parameter coordination with material supply and placement modes, increasing overall technological system configuration operating efficiency.

DEM-based optimization results show that the optimal blade inclination angle in planetary mixers is about 45°, ensuring material lifting–forward transport balance and convective mixing maximization. Convection (bulk material transport) is identified as the dominant mixing mechanism, whereas diffusion processes play a secondary role. In addition, blade geometry modification reduces mix coefficient of variation to 1.7% at the permissible level defined by ISO 18650, indicating significant homogeneity improvement and creating favourable conditions for stable pipeline transportation and efficient vibration-load compaction during structural formation.

Implementation of the described technologies in Ukraine must consider national regulatory framework and material base specifics. Since 2022, DSTU EN 206:2022 has been in force in Ukraine as an identical translation of the European standard, introducing new consistency classes (S1–S5 for slump, F1–F6 for flow), exposure classes (X0, XC, XD, XS, XF, XA), and increased concrete mix conformity control requirements. Traditional control methods based on truck-mixer sampling provide information only after mix preparation completion. Application of Viscoprobe-type systems enables real-time production-stage control directly during mixing and mix

behaviour prediction at subsequent pipeline transportation and vibration compaction stages, minimizing nonconforming product release risk.

Ukrainian aggregate characteristics also significantly influence construction mix preparation technological system configuration operating parameters. In particular, granite crushed stone with increased flaky particle content may reduce concrete mix workability and increase pipeline transportation hydraulic resistance. Forced-action mixer application compensates this effect through more intensive component mixing and denser granular skeleton structure formation, ensuring supply stability and improving subsequent vibration-load compaction efficiency.

In addition, Ukraine possesses significant technogenic raw material reserves, particularly thermal power plant fly ash and metallurgical slag, whose incorporation into concrete mixes represents an important resource-saving reserve. Mechanical activation of such additives in high-speed mixers increases their hydraulic activity and enables their use as effective pozzolanic components, ensuring 20–30% Portland cement consumption reduction and improved mix rheological characteristics during transportation and structural formation stages.

Activated mix application enables accelerated strength-development concrete production, creating prerequisites for reinforced concrete plant product heat-moisture treatment duration reduction. Hydration induction-period reduction from 6 to 2 hours increases mold turnover rate, reduces production energy consumption, and ensures more efficient placement-stage concrete mix compaction due to faster transition to a structurally stable state.

Thus, resource-saving composite steel-reinforced concrete structure formation efficiency under two-stage technology is determined by coordinated mixer operating parameters, concrete mix and construction mortar pipeline transportation system parameters, and final-stage vibration compaction modes within the technological cycle. Integrated consideration of mixer kinematic characteristics, transportation-stage medium rheological parameters, and vibration-impact dynamic parameters ensures mix homogeneity improvement, cement stone structure formation acceleration, and restored structure physical-mechanical characteristic enhancement with simultaneous specific energy and cement consumption reduction.

**Conclusions.** The performed analysis shows that resource-saving composite steel-reinforced concrete structure formation efficiency under two-stage technology is determined by coordinated forced-ac-

tion mixer operating parameters, concrete mix and construction mortar pipeline transportation system parameters, and final-stage vibration compaction modes within the technological cycle. Planetary and twin-shaft mixer application provides the required mix component mechanical activation level, manifested in cement particle deagglomeration, hydration process intensification, and 20–30% early-stage concrete strength increase, while creating prerequisites for stable pipeline transportation without homogeneity loss. It is shown that application of Viscoprobe-type automated rheological characteristic control systems enables real-time production-stage mix parameter monitoring and subsequent transportation- and vibration compaction-stage behaviour prediction

in accordance with DSTU EN 206 requirements. It is substantiated that mechanical activation of technogenic mineral additives in high-speed mixers enables 10–30% Portland cement consumption reduction, hydration induction-period shortening to 2 hours, and reinforced concrete product mold turnover rate increase, creating prerequisites for resource saving and production energy consumption reduction. The obtained results confirm the feasibility of integrated intensive mixing, controlled transportation, and rational vibration-impact mode application as inter-related elements of a unified technological system configuration for physical-mechanical characteristic improvement of composite steel-reinforced concrete structures for rapid damaged-building restoration.

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## ЕФЕКТИВНЕ ОБЛАДНАННЯ ДЛЯ СТВОРЕННЯ РЕСУРСООЩАДНИХ СТАЛЕЗАЛІЗОБЕТОННИХ КОНСТРУКЦІЙ ПРИСКОРЕНОГО ВІДНОВЛЕННЯ ПОШКОДЖЕНИХ БУДІВЕЛЬ

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У даній науковій роботі проведено аналіз сучасного стану та перспектив розвитку обладнання для приготування, транспортування та вібраційного ущільнення бетонних сумішей і будівельних розчинів у контексті його адаптації до вимог європейських стандартів, імплементованих в Україні (ДСТУ EN 206:2018, ДСТУ 9273:2024). Основну увагу приділено дослідженню механічної та механохімічної активації компонентів бетонної суміші в умовах застосування високоінтенсивних змішувачів примусової дії, а також впливу параметрів транспортування трубопровідними системами та режимів вібраційного ущільнення на структурно-реологічні характеристики сумішей і процес формування цементного каменю. Проаналізовано кінематичні схеми планетарних, двовальних і роторних змішувачів та особливості їх взаємодії з матеріалом у складі технологічних комплектів приготування будівельних сумішей. Показано можливості застосування систем онлайн-моніторингу реологічних властивостей типу Viscoprobe та методу дискретних елементів (DEM) для прогнозування поведінки суміші на стадіях змішування, транспортування та ущільнення. Обґрунтовано вплив комплексного поєднання параметрів змішування, подачі та вібраційного впливу на прискорення процесів структуроутворення та підвищення фізико-механічних характеристик бетонів, включаючи високоміцні (НРС) та надвисокоміцні (УНРС) композити. Отримані результати можуть бути використані при обґрунтуванні раціональних параметрів роботи технологічних комплектів для виготовлення ресурсоощадних сталезалізобетонних конструкцій прискореного відновлення пошкоджених будівель з урахуванням особливостей національної сировинної бази.

**Ключові слова:** бетонна суміш, будівельний розчин, змішування, транспортування, насос, вібраційне ущільнення, вібробудник, метод дискретних елементів, ресурсоощадні технології, відновлення.

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