Вісник Тернопільського національного технічного університету
https://doi.org/10.33108/visnyk_tntu
Scientific Journal of the Ternopil National Technical University
2023, № 2 (110) https://doi.org/10.33108/visnyk_tntu2023.02
*ISSN 2522-4433. Web: **visnyk.tntu.edu.ua***

UDC 621.177; 621.314

FORMATION OF INPUT INFORMATION ARRAYS FOR COMPUTER SIMULATION OF WELDED TRUSSES BEHAVIOR UNDER THERMAL FORCE EFFECTS

Yaroslav Kovalchuk; Natalya Shynhera; Yaroslav Shved

Ternopil Ivan Puluj National Technical University, Ternopil, Ukraine

Summary. *A methodological approach is proposed for detecting the behavior of welded structures under thermomechanical influences with high reliability of results using computer modeling experiments. A series of samples were produced from a batch of rolled angle bars with dimensions of 25x25x4. By applying standardized methods on the certified electro-hydraulic testing complex STM-100, experimental investigations of the mechanical characteristics of VSt3ps steel were conducted both at room temperature and within the range of technological and fire temperatures. The obtained results were subjected to statistical analysis, and an input data array for the ultimate strength and yield strength of VSt3ps steel was formed within the temperature range from +20 to +450°C. It was found that the research results follow a normal distribution law. The scattering of values for the ultimate strength is 2.1%, and for the yield strength is 2.6%, which is significantly lower than the information provided by Ukrainian National Standard and quality certificates of the material.*

Key words: *welded truss, thermal influence, temperature deformations.*

https://doi.org/10.33108/visnyk_tntu2023.02.118 *Received 09.03.2023*

Statement of the problem. Modern approaches to determine the parameters of the stress-strain state of building structures using computer modeling experiments make it possible to design complex systems with optimal safety margins for operational and emergency impacts, ensuring their sufficient strength, reliability and durability. However, considering the complex influence of these factors requires the correct formation of input information arrays for the applied software packages used in the modeling experiment. Taking into account structural features, technological parameters, operating conditions and possible emergency situations in the input data is crucial for obtaining accurate results and reliable forecasts of the strength and service life of building structures.

Having analyzed the cause of failure of load-bearing structures, specifically welded trusses, it was found that, as a rule, changes in the mechanical properties of materials under thermal effects are not sufficiently taken into account at the design stage. Welded trusses in particular can be affected not only by loads but also by high temperatures. In some cases, this is heat from the processing environment (boiler houses, energy facilities, steel mills, rolling mills, foundries, powder coating chambers), in other cases – from emergencies (in case of fire). It is under such conditions that it is essential to take into account changes in the mechanical properties of the material at high temperatures, as this can be crucial for maintaining the strength of not only the welded truss but also the building in general

Analysis of recent research. It is obvious that a temperature increase causes a decrease in the strength of most structural metals [1]. At high temperatures, there is an increase in ductility of metal alloys and creep.

Fig. 1 [1] shows graphs of changes in the tensile strength of the most common steels used in construction when exposed to high temperatures.

In Fig. 1, the change in the tensile strength of materials is shown in relative values, i.e., through the temperature coefficient of change in strength γt – the ratio of the tensile strength of materials at a given temperature to the tensile strength at a temperature of 20°C. The horizontal dashed line shows the critical value of the coefficient γt, at which the tensile strength of the material in heated state decreases to the value of the working stresses in the structure. Under such conditions, the structure will fracture. The temperature that corresponds to the loss of strength and bearing capacity of the structure is called the critical temperature.

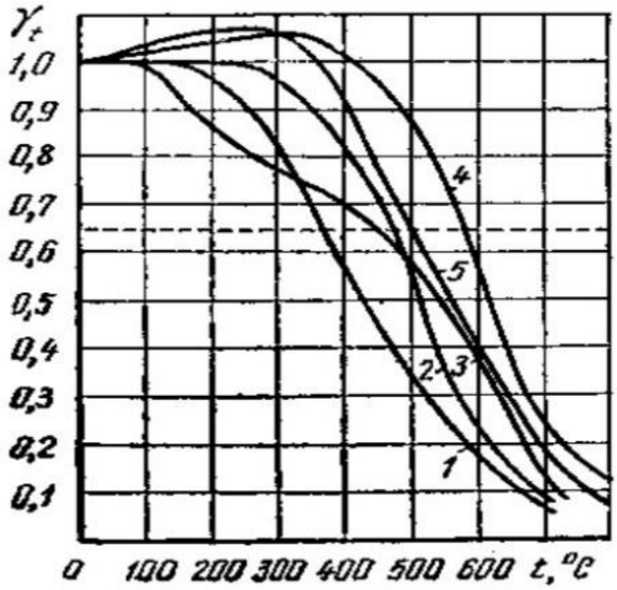


Figure 1. Changes in the tensile strength of steels when heated [1]:
1 – high-strength cold-drawn wire; 2 – ordinary cold-drawn low-carbon wire;
3 – hot-rolled steel St3, St5; 4 – low-alloy steel 25G2S; 5 – low-alloy steel 30HG2S

Based on the results of the research of other authors, it was found that the effect of temperature on the strength characteristics of structural steels is not unambiguous and has been studied mainly for fire temperatures (400...700°C).

The objective of this research is to form information arrays on the strength characteristics of the supplied batch of VSt3ps steel in the range of operating temperatures for the use of the obtained databases in computer simulation of the behavior of welded trusses under the combined action of loads and temperatures.

Statement of the problem. To meet this goal, it is necessary to make specimens, perform a full-scale force experiment for determining the strength and yield strength according to the standard methodology both at indoor conditions and at elevated temperatures, and analyze the experimental results.

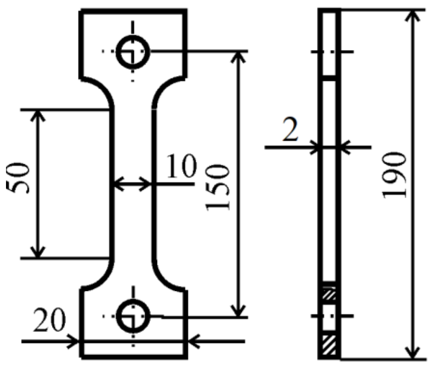
Results of the research. The most common structural material for the manufacture of welded trusses is VSt3sp steel. This material has an optimal combination of mechanical properties, weldability, and price and usually meets the structural, technological, and operational requirements for welded truss structures.

One of the key factors that ensure the accuracy of the calculation of a typical welded truss using any method is the actual strength of the material. Since the operation of trusses occurs within the limits of elastic deformation, the yield strength of the material is the determining factor for such conditions. To estimate the conditions for the onset of the limit state at the fracture point of the structure, the tensile strength of the material is the main strength indicator. If the structure is subjected to a combined effect of load and temperature, these indicators for a temperature of 200C and high temperatures form the input information array for computer simulation of the behavior of welded trusses.

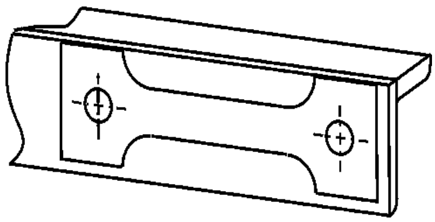
When estimating the strength properties of VSt3ps steel according to quality certificates for a rolled metal delivery batch, a wide range of scattering of the mentioned strength properties was found [3]. An even greater variation in the values of these indicators was obtained from DSTU [4].

Based on this, it is therefore obvious that when studying the behavior of an existing welded truss using the method of a computer simulation experiment, high accuracy of the results can be obtained only if the input information base is formed from the actual strength characteristics of the particular VSt3ps steel from which the truss is made. When designing a truss, it is reasonable to first obtain rolled metal for manufacturing, then determine its actual strength characteristics, and only then determine the design parameters of the truss by computer simulation.

For the full-scale experiment, a series of standard specimens (Fig. 2) were made from rolled metal products of one delivery batch of material intended for the production of welded trusses.



a



b

Figure 2. Standard specimen for experimental determination of the strength properties of VSt3sp steel under static tension: a – drawing; b – scheme of cutting from rolled angle steel

The specimen workpieces were obtained from a 6-meter long 25x25x4 mm angle steel section made of VCt3ps steel along the rolling direction (Fig. 2, b). This profile is used for the manufacture of trusses and their physical models of welded trusses.

Five specimens were tested for static tensile strength at a temperature of 20°C.

Determination of the strength parameters of VSt3ps steel to form the input database of material properties at indoor conditions was performed based on the results of the described in-situ static tensile tests.

The test results are presented in Table 1.

Table 1

Mechanical properties of VSt3ps steel at tension based on the results of full-scale tests of specimens

Strength characteristics	Specimen number				
	1	2	3	4	5
Yield strength σ_y, MPa	274	276	269	271	275
Tensile strength σT, MPa	382	384	376	381	377

The statistical processing of the experimental results was performed in accordance with standardized methods for identifying the law of their distribution and for determining whether the extreme values of the sample belong to this law. The results of tensile tests of the samples were considered as small selections.

The coherence of the experimental and theoretical distribution law of the yield strength and tensile strength random variable was checked by the Pearson criterion χ^2. The test confirmed the satisfactory agreement between the experimental and theoretical distributions and the expediency of approximating the actual distributions by Gaussian curves (normal distribution law).

The dispersion for the yield strength and tensile strength of VSt3ps steel was determined. The statistical characteristics of the mechanical properties of VSt3ps steel based on the results of full-scale experimental studies are summarized in Table 2.

The scatter of values for the tensile strength is 2.1% and for the yield strength 2.6%. Obviously, these are significantly better values than those from DSTU or rolled metal quality certificates. Using such an input information base, it is possible to obtain rather high reliable results from a computer modeling experiment.

The study of the strength properties of VSt3ps steel at high temperatures was performed on standard specimens (Fig. 2) installed in a thermal chamber (Fig. 3) using the STM-100 test complex. The temperature range for the full-scale experiment was taken from 100°C to 450°C with a step of 50°C. For each of the temperature points, 3 specimens were used. For the entire temperature range, 24 specimens were used.

Table 2

Statistical characteristics of scattering of VSt3ps steel tensile strength parameters based on the results of full-scale studies

Strength characteristics	Statistical characteristics		
	Sample average value	Sample mean square deviation	Dispersion
Strength limit	$\overline{\sigma_v}$= 380 MPa	$S_{\sigma v}$ =3.39 MPa	$D_{\sigma v}$ =11.5 MPa^2
Yield limit	$\overline{\sigma}_y$=273 MPa	$S_{\sigma y}$=2.92 MPa	$D_{\sigma y}$ =8.53 MPa^2

The values of yield strength and tensile strength for each specimen at each temperature point were obtained. Statistical processing of the experimentally obtained numerical database of results was performed similarly to that described above.

Figure 3. Thermochamber of the STM-100 test complex for determining the strength of VSt3ps steel at high temperatures

It was found that the results of the study follow a normal distribution law. Table 2 shows a sample average value of the yield strength and tensile strength at each temperature point.

Table 3

Strength characteristics of VSt3ps steel at increased temperature

Sample average value	Temperature, ^{O}C								
	20	100	150	200	250	300	350	400	450
Strength limit, $\overline{\sigma_v}$, MPa	380	372	362	334	315	292	278	265	247
Yield limit, $\overline{\sigma}_y$, MPa	273	252	246	228	215	192	185	174	165

To form a clearer picture of the effect of temperature on strength parameters, the results of the study are presented in the form of graphs (Fig. 4).

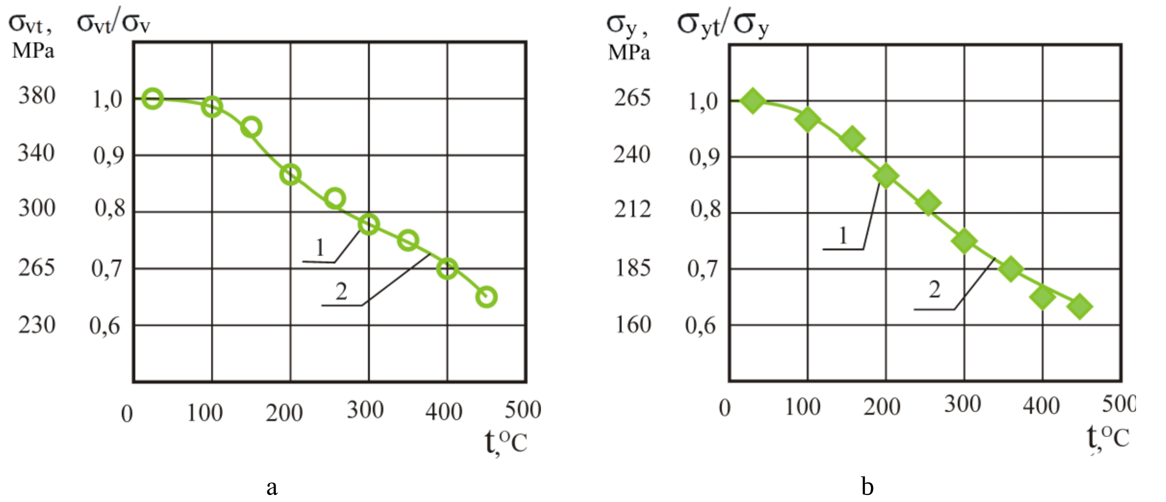


Figure 4. Changes in the tensile strength σv (a) and yield strength σt (b) of VSt3ps steel during heating: 1 – according to the results of full-scale tests; 2 – according to the results of linear approximation of experimental data

In the graphs, the sample averages of the studied values, determined by the results of statistical processing of the experimental data, are taken as real values and therefore the symbols used for sample averages are not used hereafter.

To compare the properties of VSt3ps steel at indoor temperature and at elevated temperature, Fig. 4, along the ordinate axis, next to the absolute values of strength indicators, the relative value of these values is given, i.e., through the temperature coefficient of change in strength $\gamma_t = \sigma_{vt}/\sigma_v$, as in Fig. 1. σ_{yt}/σ_y for the yield strength is presented in a similar way.

The obtained results of VSt3ps steel study were used as input information arrays for computer modeling the behavior of the studied welded truss under the complex action of force and temperature effects using the SolidWorks software package (Fig. 5).

The obtained results of the study of VSt3ps steel were used as input information arrays for computer modeling the behavior of the studied welded truss under the complex action of force and temperature effects using the SolidWorks software package (Fig. 5).

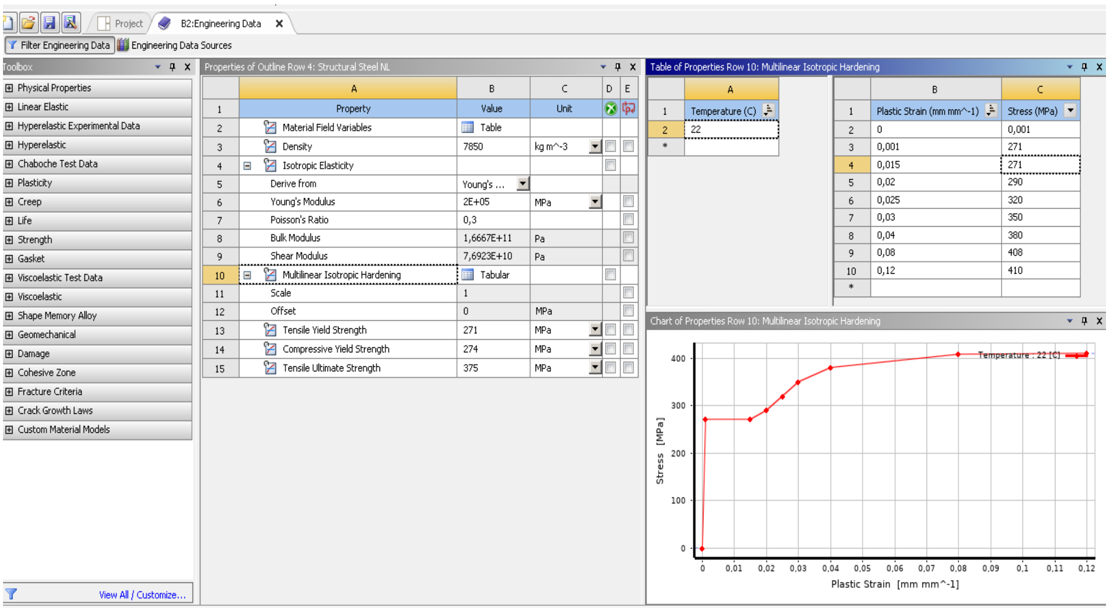


Figure 5. Engineering Data menu with the specified characteristics of VSt3ps steel

The use of the formed input information array for the SolidWorks software package in computer modeling of welded trusses behavior ensures a high degree of reliability of the results obtained on the parameters of the stress-strain state in structural elements.

Conclusions. The research proposes a methodological approach aimed at improving the reliability of the results of a computer simulation experiment when analyzing the behavior of welded trusses under thermal and power loads. The main goal of this approach was to create a reliable set of input data that would correspond to real operating conditions and fire scenarios. Based on the results of the research, an input information array was formed that includes the mechanical characteristics of VSt3ps steel, which is the main material for welded trusses. The temperature range was taken into account from normal plus values of +20°C to fire conditions, when the temperature can reach +450°C, i.e. within the limits of technological and fire conditions.

The resulting data set can be used to model the behavior of welded trusses using modern application software packages. The use of these software tools will allow to take into account the complex influence of factors and will help in the process of designing welded trusses to ensure optimal strength, reliability and durability of the structure in various operating conditions and emergency situations.

References

1. Klymenko F. E., Barabash V. M., Storozshenko L. I. Metalevy konstruktsiy. Lviv: Svit, 2002. 312 p.
2. Dolgov V. M. Mehanichny vlastyvosti i konstruktsiyna mitsnist materialiv: lektsiyniy kurs. Dnipro: NTU “Dniprovska Politehnika”, 2022. 199 p. URL: https://btpm.nmu.org.ua/ua/download/lecture-course/132%20%D0%BA%D0%BE%D0%BD%D1%81%D0%BF%20%D0%9C%D0%92%D0%9A%D0%9C%D0%9C.pdf/
3. Shynhera N. Ya. Statystychna model dlia vyznachennia zalyshkovoho resursu typovoi zvarnoi fermy pry tsyklichnykh navantazhenniakh: dys. … kand. tekhn. nauk: 01. 05.02.Ternopil, 2012. 166 p. https://doi.org/10.9790/3021-02860105
4. DSTU 2651:2005 Stal vuglytseva zvychaynoiy yakosti. Marky GOST 380-2005. Derzspozivstandart. Ukraina. Kyiv. 2006. 56 p.
5. Yang Y., Lin T., Leu L., Huang C. Inelastic postbuckling response of steel trusses under thermal loadings. Journal of Constructional Steel Research. 2008. 12 p. https://doi.org/10.1016/j.jcsr.2008.01.004
6. Rotter J., Usmani A. Fundamental principles of structural behavior under thermal effects. Fist international workshop on structures in fire. 2000. Copenhagen.

Список використаних джерел

1. Клименко Ф. Є., Барабаш В. М., Стороженко Л. І. Металеві конструкції. Львів: Світ, 2002. 312 с.
2. Долгов В. М., Механічні властивості і конструкційна міцність матеріалів: лекційний курс. Дніпро: НТУ «Дніпровська політехніка», 2022. 199 с. URL: https://btpm.nmu.org.ua/ua/download/lecture-course/132%20%D0%BA%D0%BE%D0%BD%D1%81%D0%BF%20%D0%9C%D0%92%D0%9A%D0%9C%D0%9C.pdf.
3. Шингера Н. Я. Статистична модель для визначення залишкового ресурсу типової зварної ферми при циклічних навантаженнях: дис. … канд. техн. наук: 01.05.02. Тернопіль, 2012. 166 с. https://doi.org/10.9790/3021-02860105
4. ДСТУ 2651:2005 Сталь вуглецева звичайної якості. Марки. (ГОСТ 380-2005). Держспоживстандарт України. Київ. 2006. 56 с.
5. Yang Y., Lin T., Leu L., Huang C. Inelastic postbuckling response of steel trusses under thermal loadings. Journal of Constructional Steel Research. 2008. 12 p. https://doi.org/10.1016/j.jcsr.2008.01.004
6. Rotter J., Usmani A. Fundamental principles of structural behavior under thermal effects. Fist international workshop on structures in fire. 2000. Copenhagen.

УДК 621.177; 621.314

ОСОБЛИВОСТІ ФОРМУВАННЯ ВХІДНИХ ІНФОРМАЦІЙНИХ МАСИВІВ ДЛЯ КОМП'ЮТЕРНОГО МОДЕЛЮВАННЯ ПОВЕДІНКИ ЗВАРНИХ ФЕРМ ПРИ ТЕРМОСИЛОВИХ ВПЛИВАХ

Ярослав Ковальчук; Наталія Шингера; Ярослав Швед

Тернопільський національний технічний університет імені Івана Пулюя, Тернополь, Україна

Резюме. *Використання методики комп'ютерного моделювання для виявлення поведінки зварних ферм при комплексній дії на них навантажень і температури, зазвичай, дає результати з недостатнім ступенем достовірності. Визначальною причиною цього є широкий розкид параметрів міцності конструкційних матеріалів, вказаний у державних стандартах. За результатами досліджень інших авторів виявлено неоднозначний вплив температури на характер зміни показників міцності матеріалів при їх нагріванні. Запропоновано методичний підхід для виявлення поведінки зварних ферм за умов термосилових впливів з високою достовірністю результатів при використанні комп'ютерного моделюючого експерименту. З поставленої партії вальцьованого кутника 25х25х4 виготовлено серію зразків. За стандартизованими методиками на сертифікованому електрогідравлічному випробувальному комплексі СТМ-100 виконано натурні дослідження механічних характеристик сталі ВСт3пс як для умов кімнатних температур, так і в діапазоні технологічних і пожежних температур. Виконано статистичне опрацювання отриманих результатів і сформовано вхідний інформаційний масив границі міцності й границі текучості сталі ВСт3пс у діапазоні температур від +20 до +450*^{O}*С. Побудовано графічні залежності зміни границі міцності й границі текучості сталі ВСт3пс у цьому температурному діапазоні як в абсолютних, так і у відносних координатах. Виявлено, що результати досліджень підпорядковуються нормальному закону розподілу. Розсіювання значень для межі міцності становить 2,1%, а для межі текучості 2,6%, що значно менше, ніж за інформацією ДСТУ та сертифікатів якості матеріалу. Запропоновано використання отриманих результатів для визначення параметрів граничного стану зварних ферм як на етапі їх проектування, так і впродовж експлуатації. Сформована інформаційна база може бути використана для дослідження несучої здатності інших конструкцій, які сприймають одночасно навантаження і температурний вплив.*

Ключові слова: *зварна ферма, тепловий вплив, температурні деформації.*

https://doi.org/10.33108/visnyk_tntu2023.02.118 *Отримано 09.03.2023*